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Some geological and magnetic characteristics of buried and resurrected precambrian hills of Southeastern Missouri

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SOME GEOLOGICAL AND MAGNETIC CHARACTERISTICS

OF BURIED AND RESURRECTED PRECAMBRIAN HILLS

OF SOUTHEASTERN MISSOURI

By

James Edward Palmer — 1928 –

A

DISSERTATION

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INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

The major purpose of this investigation was to determine by a comprehensive study various geological and magnetic characteristics of buried and resurrected Precambrian hills of the Central Ozarks. A second important objective was the determination of characteristics which might aid in the location of buried Precambrian hills. A final objective was the testing of the magnetic surface integration method for identification and determination of depth of buried Precambrian hills.

This investigation is limited to buried and resurrected Precambrian hills of the Central Ozarks. It is concerned primarily with the structure and stratigraphy of sediments adjacent to buried and resurrected Precambrian hills, and magnetic anomalies associated with the hills. Other geological characteristics are considered in less detail.

Six areas within the Central Ozarks were selected for detailed mapping and study. The structure and stratigraphy of Upper Cambrian and Lower Ordovician sediments were examined in order to determine environments of deposition, the origin of peripheral dips, and the origin of tangential and radial jointing noted during the study. Magnetic characteristics were surveyed at several localities, and efforts were made to reproduce the magnetic fields associated with the Precambrian hills by use of the surface integration method. Configuration of the Precambrian topography and its relationship to overlying and surrounding sediments was also considered.

The petrology and structure of Precambrian igneous rocks of which the hills are composed are not considered in detail in this dissertation. In addition geochemical and other geophysical aspects remain to be examined in greater detail by future workers.

LOCATION OF STUDY AREAS

A number of factors were considered in selecting areas for detailed study. The following were considered to be of primary importance:

1. Each area must contain a buried or resurrected Precambrian hill.
2. The distribution of the selected areas should be such that they represent an adequate sampling of these features in the Central Ozarks region.
3. Where possible, areas should be selected where good exposures of bedrock are present, or where drill hole information is available.
4. Areas should be selected in which Precambrian hills display all stages of exposure, from complete burial to fairly complete resurrection.
5. The selected areas should contain as much of the Upper Cambrian-Lower Ordovician stratigraphic section as possible in outcrop adjacent to buried hills.
6. The number of areas selected must be limited with regard to the time available for detailed mapping and study.

With these considerations in mind, six areas were selected to include approximately thirty square miles of the Central Ozarks region of southeastern Missouri (see Figures 1 and 2). The following is a brief description of the locations of the six selected areas.

The Czar Knob area is approximately two miles north of the town of Viburnum, Missouri, within the confines of the Clark National Forest. The Eminence Knob area is one mile north from the town of Eminence, Missouri, and approximately fifty miles north of the southern boundary of the state. The Taum Sauk area is at the site of the Union Electric Company Taum Sauk Hydroelectric Project, approximately twenty miles southeast of Ironton, Missouri, on the East Fork of the Black River. The Caledonia area includes the northwest portion of the town of Caledonia,

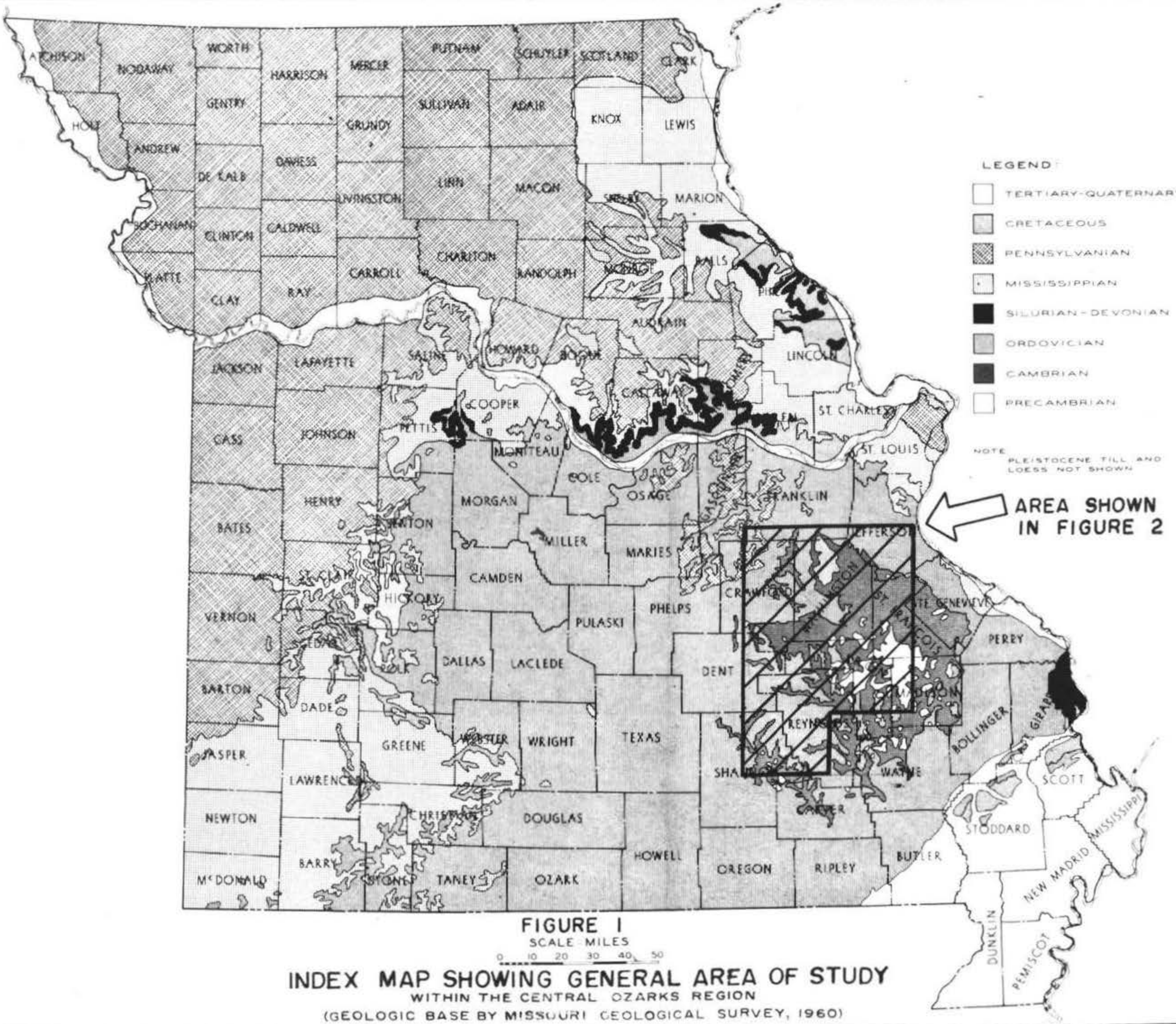

FIGURE 1

INDEX MAP SHOWING GENERAL AREA OF STUDY
WITHIN THE CENTRAL OZARKS REGION
(GEOLOGIC BASE BY MISSOURI GEOLOGICAL SURVEY, 1960)

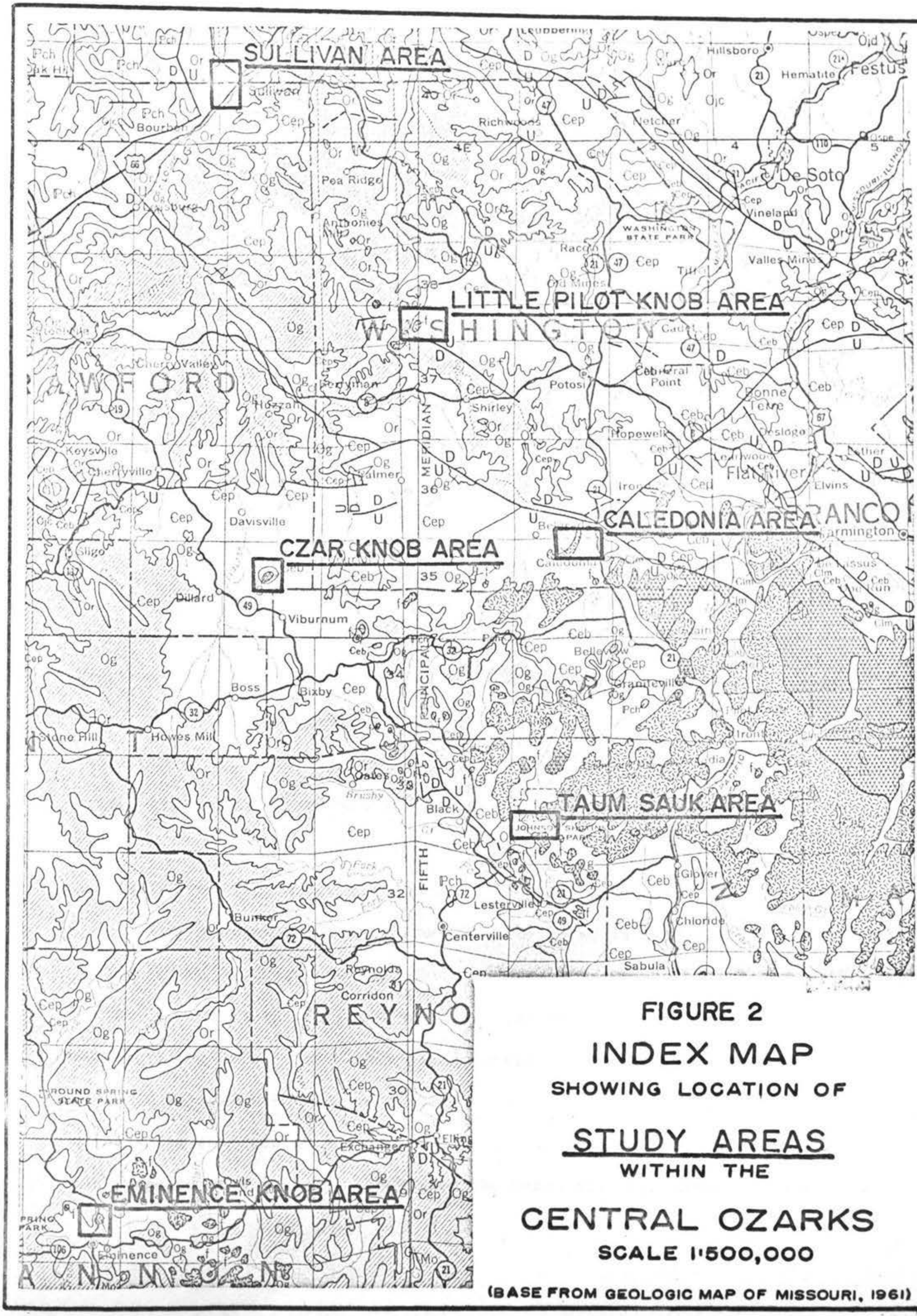

FIGURE 2
INDEX MAP
SHOWING LOCATION OF
STUDY AREAS
WITHIN THE
CENTRAL OZARKS
SCALE 1:500,000
(BASE FROM GEOLOGIC MAP OF MISSOURI, 1961)

Missouri, and extends northward to the vicinity of the Big River. The Little Pilot Knob area is approximately five miles from Shirley, Missouri, and eight miles west of the city of Potosi, Missouri. The Sullivan area lies sixty miles west of St. Louis, Missouri, on United States Highway 66, and includes the western portion of the city of Sullivan, Missouri.

All of these areas are normally accessible by automobile on all-weather roads. More detailed discussions of location and accessibility will be given in the chapters which contain discussions of the individual areas.

METHOD OF STUDY

The study began with a comprehensive review of the geological and magnetic literature relating to the subject of buried and resurrected Precambrian topography. Detailed field mapping of the six selected areas was completed. Subsequently, magnetic surveys were completed in three of the study areas. The laboratory portion of the investigation included lithologic studies, analysis of joint patterns adjacent to the buried hills, a study of peripheral dips, and the computation of magnetic fields associated with the hills through use of a digital computer.

The field work for this study was completed in a thirteen month period extending from June 1962 through June 1963. Approximately one-half of the time was spent in field work, and the remainder was devoted to compilation of the report. The field portion of the study consisted of geologic mapping with the aid of U. S. Geological Survey topographic quadrangles enlarged to a scale of 1:6000. In the Taum Sauk area, a base map prepared at a scale of 1:6000 for the Union Electric Company by the

Surdex Corporation of St. Louis, Missouri, was used. These maps were photographically reduced to 1:24000 scale for presentation in this study. The field work included:

1. Delineation of rock units on the base maps.
2. Plotting of joints, strikes, and dips.
3. Examination and sampling of certain lithologic units.
4. Detailed magnetic surveying by use of a Jalander flux gate vertical intensity magnetometer.

The laboratory portion of the study included the following:

1. Preparation of base maps at a scale of 1:6000 by tracing optically projected enlargements of U. S. Geological Survey topographic quadrangles.
2. Petrographic examination of twelve thin sections were made from hand specimens selected from the collection of specimens of the various lithologic units. These were studied in order to determine environments of deposition.
3. Photomicrographs of thin sections of representative rock samples were prepared with the aid of Leitz Panphot equipment and contact prints made from 3¼ by 4 inch film sheets.
4. Magnetic susceptibilities were determined for four crushed samples obtained from the two resurrected Precambrian hills for which magnetic calculations were made.
5. Mathematical computation and analysis of two magnetic anomalies were made by use of the IBM 1620 digital computer of the University of Missouri at Rolla.
6. The final geologic maps were prepared at a scale of 1:24000.

A detailed lithologic study of the Union Electric Company Taum Sauk Cut was completed and approximately seventy-five rock samples were collected. Both field and laboratory descriptions of these samples were completed and thin sections were cut from twelve of the more significant samples. This study was directed toward the determination of environment of deposition of the exposed dolomite section, in order to determine the origin of the steep dips exposed in the cut. In addition, types and characteristics of sediments adjacent to all studied Precambrian knobs were noted.

Rate of decrease in dip with increasing distance from exposed knobs was determined at three localities in order to detect lateral expression of the knobs. The persistence of peripheral dips into overlying sediments was considered, both in the areas studied and at several other localities.

A Paulin altimeter was used in mapping on a marker horizon (Gunter Sandstone Member of the Gasconade Formation) in the Eminence area in order to test this method in determining possible Precambrian topographic trends. This method is based upon the assumption that the Gunter Sandstone Member elevation reflects the elevation of the underlying Precambrian surface. In every mapped area, an effort was made to interpret the configuration of the buried Precambrian surface from the available geologic and magnetic evidence.

Approximately one thousand sets of joints were mapped within the six areas in order to determine a possible relationship between joint patterns and the Precambrian topography.

Vertical intensity magnetic surveys were completed in the Little Pilot Knob area, the Eminence area, and the Sullivan area. The magnetic anomalies noted during these surveys are considered in light of other geologic data obtained in detailed field mapping of the areas.

Models for magnetic calculations were prepared from subsurface data for the Czar Knob, Little Pilot Knob, and a suspected buried knob immediately east of Little Pilot Knob. The total magnetic field intensity was calculated for these knobs by use of the surface integral method. These calculations were completed through the use of the University of Missouri at Rolla IBM 1620 digital computer. The total magnetic fields obtained were compared with the actual field as obtained through aero-magnetic surveys in the areas.

References to previous work are made in the introduction and throughout the report. Where warranted, certain previous concepts and observations are re-evaluated in the light of data obtained during the present study.

ACKNOWLEDGMENTS

The writer here wishes to acknowledge a debt of gratitude to the many individuals who have offered assistance during this study. Dr. Paul Dean Proctor, Dean of the School of Science of the University of Missouri at Rolla, suggested the problem and provided invaluable guidance while it was being undertaken. He supervised the writing of the manuscript and offered many valuable suggestions.

Dr. Thomas R. Beveridge, Chairman of the Department of Geological Engineering and Geology at the University of Missouri at Rolla, and former Director of the Missouri Geological Survey and Water Resources, made available the facilities of the Survey, and provided financial support for field work connected with the study. Without such support the project could not have been completed. Dr. Beveridge also read the manuscript of this report. Grateful thanks are given for financial help from the V. H. McNutt Foundation in the last stages of this research.

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Douglas R. Stark of the Missouri Geological Survey and Water

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The writer wishes to thank also many persons not here listed individually, associated with the University of Missouri at Rolla or the Missouri Geological Survey and Water Resources, who generously assisted in this undertaking.

PREVIOUS WORK

A fairly substantial amount of literature is available on various aspects of the Precambrian topography of Missouri, and the expression of Precambrian relief in the overlying sedimentary section. However, these previous works were, in many cases, somewhat generalized in their treatment of the subject of Precambrian topography. The most comprehensive reports on the subject were completed by C. L. Dake and Josiah Bridge (1930) in their outstanding studies of the Edgehill, Potosi, and Eminence and Cardareva quadrangles. A substantial amount of data have become available in the intervening years since these two publications.

In the discussion of previous work, only those publications regarded as of major significance in the present study are included. More detailed comments are made within the body of the report concerning some publications in this section, and references are made to others that are not mentioned here. A review of the literature on differential compaction is presented within the chapter concerning peripheral dips of Precambrian knobs. Discussion of the literature on magnetic interpretation and analysis is included in the section on magnetic applications.

One of the earliest published references to Precambrian topography and its relation to overlying sediments in southeast Missouri was that by

Pumpelly in 1873 (pp. 8-9). Pumpelly stated,

> they the [Precambrian hills] form an archipelago of islands in the Lower Silurian [sic] strata which surround them as a whole, and separate them from each other.................. The porphyries and granites had undergone an enormous amount of erosion before the limestones were formed; an amount at least several times as great as that they have suffered since that remote time.

Pumpelly correctly identified the knobs as erosional features buried by younger sediments now assigned to the Upper Cambrian.

By 1894 the concept of a Precambrian erosional topography covered by younger sediments seems to have become firmly established. Haworth (1894, pp. 99-100) stated,

> they [the Precambrian rocks] were subjected to prolonged degradational action, and it was upon their deeply eroded surface that the sandstone and limestones were laid down during early Paleozoic times, probably burying to a very considerable depth many and perhaps all of the old peaks and elevations.

Haworth correctly assigns the basal sediments to the Cambrian System. He presents a detailed discussion of evidence indicating the Precambrian knobs are of erosional origin, rather than intrusive bodies into the sedimentary section.

In the biennial report of the State Geologist of Missouri for the year 1928, Josiah Bridge and C. L. Dake described some of the characteristics of buried and resurrected Precambrian hills and present the first discussion of the problem of origin of peripheral dips. In this discussion Bridge and Dake suggest that the peripheral dips are largely initial, but refrain from drawing a definite conclusion to that effect.

Bridge (1930, pp. 151-168) in a more complete discussion of the structures caused by buried Precambrian topography, describes a number of examples of buried and resurrected Precambrian hills. He presents a structure contour map on the top of the Gunter Sandstone Member of the Gasconade Formation over a portion of the Eminence and Cardareva Quadrangles. He concludes that dips adjacent to the Precambrian hills are initial, and not the result of post-depositional compaction and solution.

Dake (1930, pp. 185-191) presents additional examples of buried and resurrected Precambrian hills of the Central Ozarks. Dake and Bridge (1932) amplify and restate their observations and conclusions presented in their earlier reports.

Tarr (1936) presents a very comprehensive study of the origin of lead deposits in southeast Missouri. In this study he describes a number of primary and secondary features of the Upper Cambrian and Lower Ordovician sedimentary section which are related in some cases to Precambrian topography.

Wagner (1947) gives a rather detailed account of the lithology of the Bonneterre Formation including a description of typical reef development in the formation. He discusses the importance of buried Precambrian topography in the search for lead deposits.

James (1949 p. 22) in a detailed study of the Fredericktown area, concludes that lead deposits formed in the Bonneterre Formation in fractured zones in areas closely adjacent to Precambrian hills. James further concludes that the distribution of Lamotte Formation was related to Precambrian relief, and the formation has been the "feeder" channel of mineralizing fluids.

In a report concerning structural environments of lead deposits of southeast Missouri, James (1952) describes a local fracture system in sediments adjacent to Precambrian knobs which seem to be closely related to the knobs. James states,

> the fractures bend with the curvature of the knob or ridge, but they diverge where this curvature is sharp. The fracturing in the mines, and the projection of it beyond the mine openings, develops the picture of a band of locally controlled fracturing in the sediments along the flank of a knob or ridge.

In general, he concludes that the fractures parallel the gross configuration of the knobs, and are important in the localization of lead deposits at some localities.

Ohle and Brown (1954) offer a detailed discussion of genesis of Lead Belt ore deposits. The authors discuss in detail lithology and sedimentary structures within the Bonneterre Formation which influenced the localization of lead deposits. They list several Lead Belt mines in which Precambrian hills are very important in the control of mineralization.

In a study of sedimentary breccias of southeast Missouri, Snyder and Odell (1958) describe collapse breccias which in some cases are closely related to buried Precambrian hills and ridges. These brecciated zones, apparently due to higher porosity and permeability, were very important in the localization of ore bodies.

Zarzavatjian (1958) attempted the detection of buried basement highs by airphoto drainage pattern analysis. He reports the successful location of one buried hill and indicates the possible location of two others. In general, however, Zarzavatjian reports only partial success in the application of this method.

Allingham (1960) in a partly completed study of the interpretation of aeromagnetic anomalies in southeast Missouri, states that some basement ridges and hills can be successfully located and defined through the use of magnetic surveys. He describes a number of different types of magnetic anomalies and their associated geologic conditions.

GENERAL GEOGRAPHY OF THE OZARK UPLIFT

PHYSIOGRAPHY

In its most restricted sense, the Ozark Uplift occupies a broad area of approximately 8,100 square miles in southeast Missouri. It lies at the eastern extremity of the larger Ozark Plateau Province, which occupies most of the southern half of Missouri, and extends into Arkansas and Oklahoma. It is bounded on the east and north by the Interior Lowlands Province, on the west by the Salem Platform, and on the south by the Boston Mountains of Arkansas.

Throughout much of the central portion of the Ozark Uplift, Precambrian rocks occur at elevations well above sea level. The highest point in Missouri, Taum Sauk Mountain, in Iron County, is located on Precambrian rhyolite porphyry at an elevation of 1,772 feet above sea level. In Iron, Madison, and St. Francois Counties, Precambrian rocks form the St. Francois Mountains which commonly attain elevations above 1,500 feet. The region of maximum elevation of the Ozark Uplift lies within the St. Francois Mountains.

Sedimentary rocks of Upper Cambrian and Lower Ordovician age generally occupy the lower elevations surrounding the higher Precambrian peaks and ridges. Lower Precambrian hills are completely buried by sediments.

Throughout the area of the Ozark Uplift, broad hilly areas, smaller peaks and hills, and small exposures of the Precambrian surface have been resurrected by erosion and are surrounded by sediments. These exposures of the Precambrian surface are ubiquitous, and number well over one thousand, if smaller outcrops are included. An additional large number of these Precambrian prominences remain buried beneath the sedimentary section.

RELIEF

The St. Francois Mountains area is of high relief. From the maximum elevation of 1,772 feet above sea level, elevations range downward to a minimum of less than 500 feet within some stream valleys in the southern portion of the region. In general, elevations average approximately 1,000 feet above sea level.

DRAINAGE

The Black River and the St. Francis River provide drainage of the Uplift area on its southern margin. These rivers collect water from a large number of tributary creeks of the Southern Ozark region, and flow southward into Arkansas. The Current River drains the southwestern margin of the Uplift and similarly drains into Arkansas. The Meramec River drains much of the north and northwest portion of the Uplift, and drains eastward into the Mississippi River. The northeast margin of the Ozark Uplift is drained by the Big River and a large number of well-developed northeastward-flowing creeks which empty into the Mississippi River. The southeast margin of the Uplift is drained by the Whitewater River, the Castor River, and several large southeastward flowing creeks. These streams flow into the broad low swampy area of the Missouri "boot-heel" where their identity is lost.

Streams flowing along the western margin of the Uplift are generally tangential to the Uplift. Streams located on the north, east, and south flanks exhibit a gross radial drainage pattern. All of the streams can be classified as consequent, as their courses appear to be due to the general slope of the flanks of the Uplift.

CLIMATE

The annual average temperature in the Central Ozarks is 55°F, according to record kept by the U. S. Weather Bureau. The coldest month is January, with a monthly normal mean of approximately 35°F. The warmest month is July, which has a monthly normal mean temperature of approximately 80°. The extreme ranges in temperature are from about 25°F. below zero to about 110°F. above zero, although these extreme values are rarely reached.

Climatic changes in the region lag approximately one month behind the sun's changes in latitude. The sun reaches its highest latitude on June 20, with the warmest weather occurring in July. Correspondingly the sun drops to its lowest latitude on December 21, with the coldest weather occurring in January. The growing season in the Central Ozarks area is approximately 210 days.

The mean annual precipitation in the area is forty-five inches (Visher, 1954, p. 197). The wettest month is January which has a mean monthly precipitation of five inches. The driest month is July, with mean monthly precipitation of only three inches. The monthly average precipitation in the area is slightly less than four inches. In comparison with the remainder of the state of Missouri, precipitation is slightly greater in the winter and slightly less during the summer months. The prevailing winds are westerly and southwesterly.

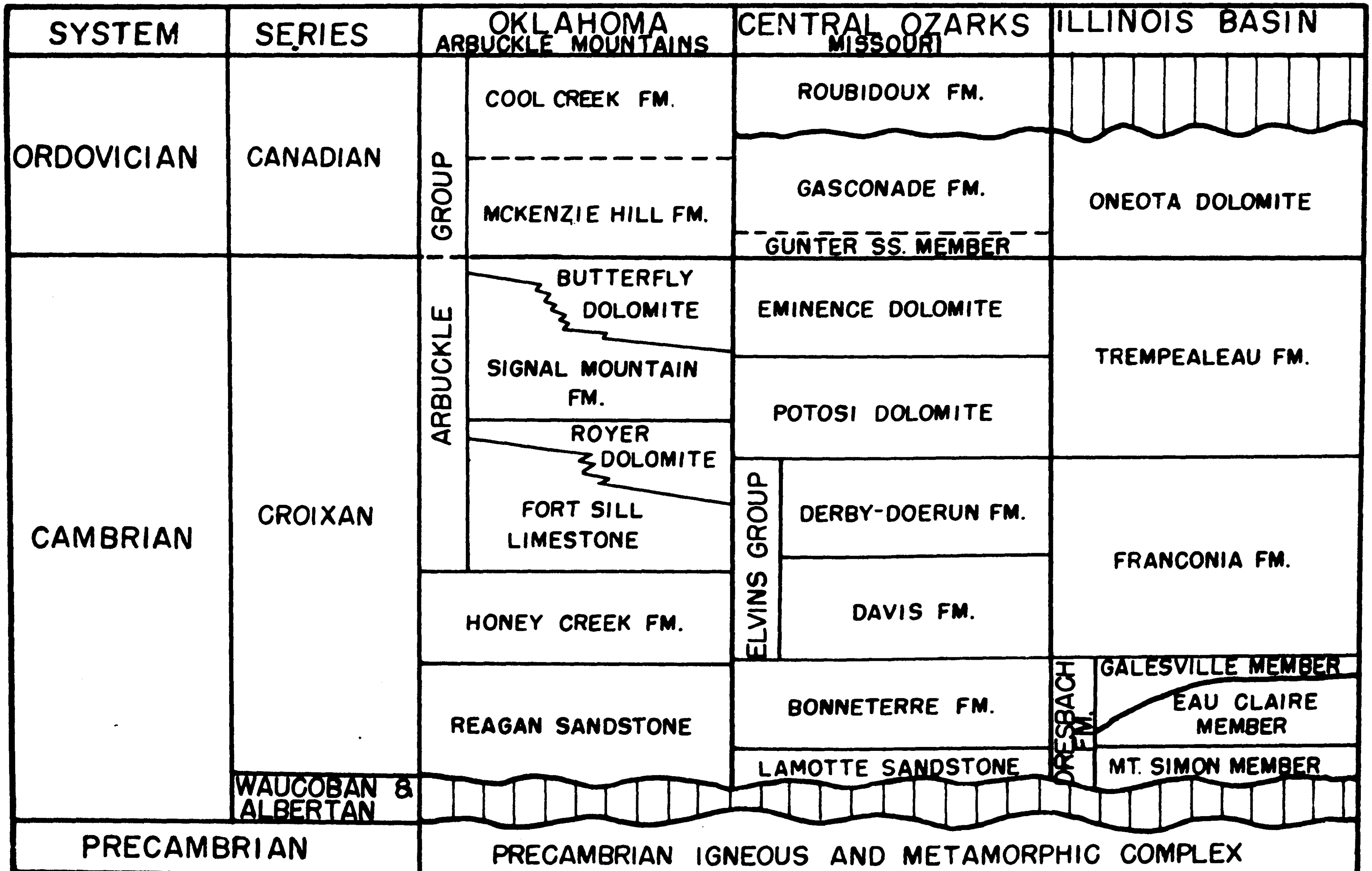
REGIONAL GEOLOGY OF THE CENTRAL OZARKS

GENERAL STRATIGRAPHY

Sedimentary rocks within the Central Ozarks are of Upper Cambrian and Lower Ordovician age. This sedimentary sequence has been subdivided into eight formations almost entirely on the basis of lithology. Fossils are rare. These and their stratigraphic equivalents in adjoining states are shown in Figure 3. The oldest sedimentary unit present is the Lamotte Formation, and the youngest, largely removed by erosion, in many areas, is the Roubidoux Formation. The eight formations have an average aggregate thickness of approximately 1,500 feet at localities where the complete section is present. The two thickest units are the Bonneterre and Potosi Formations which have average thicknesses of 250-400 feet. The thinnest units are the Derby-Doerun Formation and the Roubidoux Formation, which have average thicknesses of 100 to 200 feet.

The sedimentary section of the Central Ozarks is strongly affected by Precambrian topography. Where deep Precambrian valleys are present, the sedimentary section shows a pronounced valleyward thickening. Conversely as the sedimentary units approach Precambrian hills, they undergo a marked thinning to the extent that some units pinch out entirely. This is particularly true of the Lamotte Formation, which pinches out adjacent to a large number of Precambrian hills.

In addition to controlling the volume of sediments, the Precambrian topography to a large extent, determined the type of sedimentation. In particular, the reef structures of the Lower Paleozoic seem to have formed in many areas where shallow water conditions existed due to Precambrian



STRATIGRAPHIC CORRELATION OF UNITS CONSIDERED IN DISSERTATION AREA
MODIFIED AFTER CAMBRIAN AND ORDOVICIAN CORRELATION CHARTS (G.S.A. BULLETIN, 1944 & 1954)
FIGURE 3

highs. In local areas, the Precambrian hills contributed large volumes of arkosic material to the sedimentary section primarily during Lamotte, Bonneterre, Davis, and Derby-Doerun time. These arkosic sediments are normally restricted to the immediate vicinity of the knobs and rarely extend more than one mile into adjacent sediments. By Potosi time many of the knobs had been buried to such depths that they contributed only minor quantities of material to the surrounding sediments.

Ojakangas (1960) in a study of stratigraphy and petrology of the Lamotte Formation, reports a source area to the northwest for this formation; and presents a general discussion of regional factors controlling its distribution. Carver (1961) recognizes three broad depositional provinces of the Roubidoux Formation adjacent to the present granite outcrops of the Ozark dome. However, little has been published concerning local depositional environment adjacent to Precambrian hills.

The sedimentary section of the Central Ozarks can be roughly divided into 75 percent carbonates (predominantly dolomite), 20 percent clastics, found primarily within the Lamotte, Davis, Gasconade and Roubidoux formations, and about 5 percent quartz druse and chert. The Eminence and Potosi formations contain significant amounts of silica in the form of quartz druse, and some zones of the Gasconade Formation are reported to be more than 50 percent chert (Martin, et al, 1961, p. 22).

The Central Ozarks stratigraphic section has been studied in detail and described by numerous workers. It would be redundant to present a detailed discussion of this subject thoroughly covered by others. However, the brief summary below is included for sake of completeness.

Precambrian Rocks

The Precambrian igneous rocks of the Central Ozarks consist of three main types: felsites, granites, and basic intrusives. The felsites, regarded as the oldest, are primarily rhyolite with limited occurrences of trachyte. They frequently exhibit flow structures and are often porphyritic. The rocks are usually strongly jointed and form the highest prominences in areas of outcrop.

The granites, which are intrusive into the felsites, are predominantly red to pink and medium to coarse grained. They are massive, with no evidence of any schistose or gneissic structure. Most of the granites are very low in iron and dark minerals (Hayes, 1961, p. 12).

Basic intrusives occur in small dikes and stocklike bodies at a number of localities within the Central Ozarks. However, none is reported by Bridge in the Eminence and Cardareva quadrangles (Bridge, 1930, p. 63). They consist of gabbros, basalts, and diabase porphyries and occur in both the felsites and the granites of the St. Francois Mountains. All of the above rock types are unconformably overlain by the basal Late Cambrian Lamotte Formation.

Cambrian System

Lamotte Formation. The Lamotte Formation overlies unconformably the deeply eroded Precambrian surface within the Central Ozarks. The largest portion of the unit is composed of medium to fine-grained quartz sand which contains substantial iron in the form of oxides and hydrated oxides. It ranges from light gray through yellow, reddish brown, and red, depending upon the amount and degree of oxidation and hydration of the associated iron. Where the formation approaches Precambrian hills, it frequently grades into fine to coarse arkosic conglomerates. Other facies of the formation are red to purple silt and shale, and lenses of arenaceous dolomite. The formation reaches a maximum thickness of 500 feet within deeper basins of the Ozarks (Hayes and Knight, 1961, p. 15). Its nominal thickness is about 200 feet.

Bonneterre Formation. Because nearly all of the major lead deposits of the southeast Missouri Lead Belt are localized within its lower portion, the Bonneterre Formation has received far more attention and study than any other sedimentary unit within the Central Ozarks. The formation is predominantly dolomite within the Central Ozarks. Koenig (1954, p. 51) has identified 100 percent limestone facies away from the central region. Basal beds of the unit become increasingly sandy as the transitional contact with the underlying Lamotte is approached. The formation is characteristically medium to finely crystalline, light gray to buff dolomite. Some of the upper beds are coarsely crystalline and light milky gray. It is usually thick to massively bedded. The formation approaches 440 feet in thickness in the Lead Belt (Koenig, 1954, p. 18).

Elvins Group: Davis Formation. The Davis Formation is an excellent marker horizon throughout the Central Ozarks because of its distinctive lithologies and a reliable faunal zone in its upper portion. It consists of a series of thin and interbedded dolomitic limestone, limestone conglomerates, shales, and lesser amounts of very fine-grained sandstone. It varies greatly in lithology and at some localities, the formation is almost entirely medium-bedded dolomite. Distinctive sedimentary features which make the formation readily identifiable are the flat-pebble and edgewise conglomerates, and its thin-bedded, silty, and shaly character. The flat-pebble and edgewise conglomerates are believed by some workers to be the remnant of sun-cracked surfaces which have been broken and agitated by wave action, and preserved in this state by subsequent deposition (Twenhofel, 1950, p. 303).

An Eoorthis zone, first described by Dake (1936, p. 89), and located approximately 35 feet below the top of the formation, is a reliable marker of this interval in the Central Ozarks. The Davis Formation has an average thickness of 170 feet (Hayes and Knight, p. 18).

Elvins Group: Derby-Doerun Formation. The Derby-Doerun Formation is one of the thinnest formational units of the Central Ozarks. In lithology it is very similar to the underlying Davis Formation and is composed of thin and medium-bedded dolomite alternating with thin-bedded siltstone and shale. The upper portion of the formation is characterized by the presence of glauconite. The formation is conformable with the underlying Davis, and has a thickness of approximately 150 feet.

Potosi Formation. The Potosi Formation consists of medium to finely crystalline light brown dolomite, and contains an abundance of quartz druse, and chert. The formation is massively bedded and in many areas has no visible bedding planes. The presence of abundant quartz druse float permits ready recognition of the formation. Its thickness ranges to more than 300 feet, with an average of about 250 feet.

Eminence Formation. The Eminence Formation is very similar in gross appearance to the underlying Potosi Formation, with which it is conformable. It is light gray, medium to coarsely crystalline, and generally massively bedded. Bedding planes are nearly as rare within this formation as in the underlying Potosi. It is distinguished from the Potosi by its lighter color and more coarsely crystalline dolomite. Also, it is significantly less cherty than the Potosi. Quartz druse is present within the Eminence Formation, but in much less volume than in the Potosi, and the quartz crystals are less well developed. In general, the two formations are easily confused, and can be distinguished only by careful study of their respective lithologies. The Eminence Formation has an approximate thickness of 200 to 250 feet.

Ordovician System

Gasconade Formation. The Gasconade Formation is primarily a light brownish gray, very cherty dolomite. A thin but persistent regional sandy horizon named the Gunter Sandstone Member is present at the base of the Gasconade and serves as an excellent marker horizon. The basal portion above the Gunter Sandstone Member is composed of more than 50 percent chert. The upper portion of the formation is predominantly finely crystalline dolomite and contains less chert (Martin, 1961, p. 22). The formation has a thickness of about 175 feet. Bluff and ledges are characteristic. Bedding planes of the unit are very irregular. The formation is also noted for *Cryptozoon* reef structures, which occur in bedded zones within the upper portion of the unit.

Roubidoux Formation. Within the Central Ozarks the Roubidoux

Formation is composed of sandstone, dolomitic sandstone, and cherty dolomite. The formation seldom contains more than 50 percent sandstone, although sandy zones may be scattered throughout its thickness. The sandstone is composed of medium to fine-grained quartz sand which is normally subrounded and frosted (Martin, 1961, p. 22). Although the Roubidoux is sparingly fossiliferous over most of the Central Ozarks, Heller (1954, p. 7) collected and described twenty genera and twenty three species from the unit. Thickness of the formation ranges from 105 feet to more than 250 feet in the southwestern part of the Ozark region. Sandstones of the Roubidoux Formation are gray to brown on weathered surfaces, and buff to white on fresh fractures. Dolomite of the formation ranges from light gray to light brown. Bedding character is variable, with most units being medium to thick-bedded.

STRUCTURAL HISTORY OF THE OZARK UPLIFT

Precambrian Structural History

Precambrian rocks of Missouri give evidence of a complex structural history. Two early extrusions of felsites are identified, followed by erosion and subsequent extensive folding and faulting. The intrusion of a large composite pluton of granitic composition into the felsite sequence followed the orogenic episode. A final period of basic intrusions preceeded a long interval of erosion which persisted until Late Cambrian time. Regional tilting to the southwest and faulting occurred during this long period of erosion.

The early structural history of the Ozark Uplift has been described by Snyder and Wagner (1961, pp. 84-94). The first identified event was the extrusion of felsites on an unknown older surface. Original thickness and

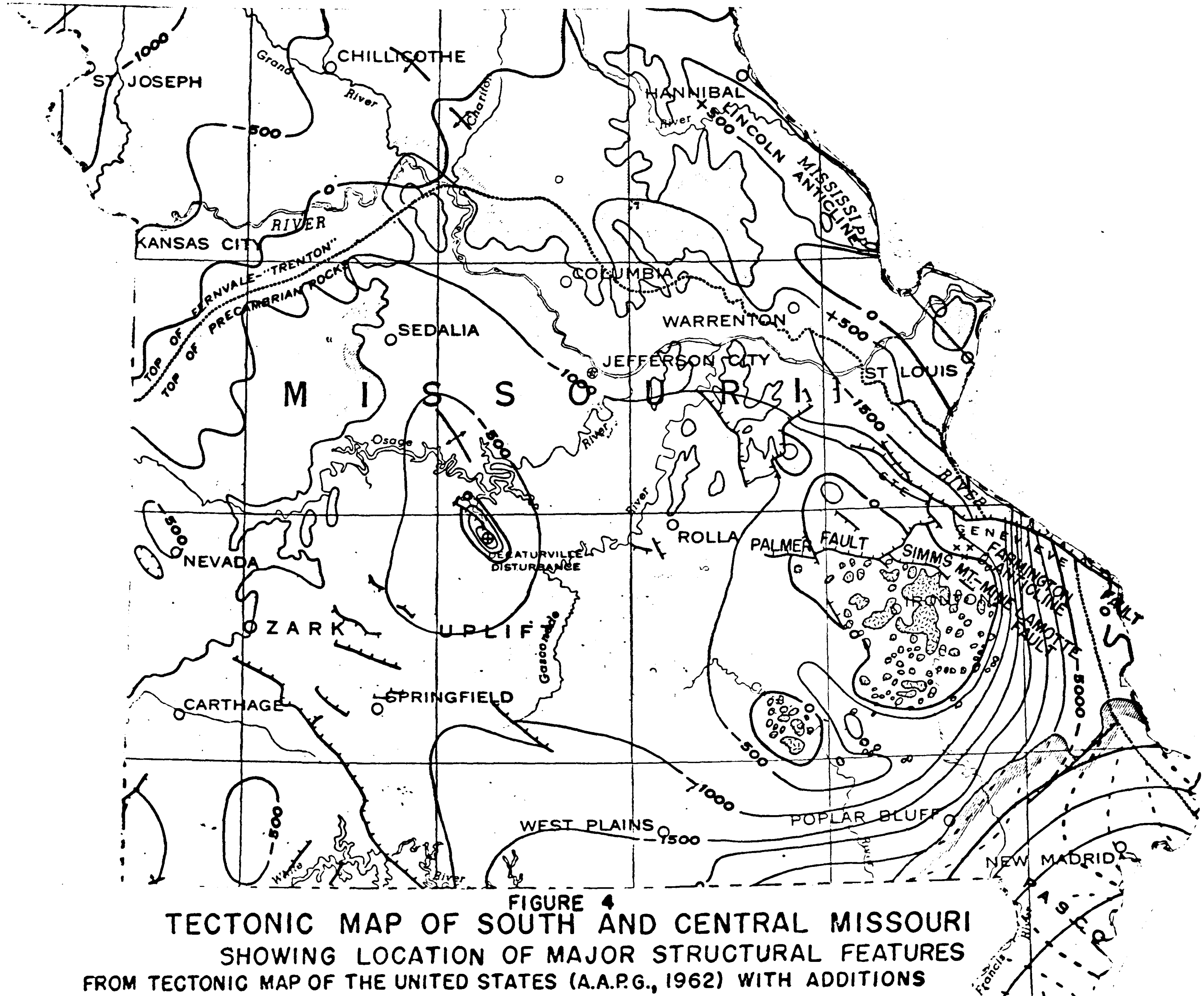


FIGURE 4

TECTONIC MAP OF SOUTH AND CENTRAL MISSOURI

SHOWING LOCATION OF MAJOR STRUCTURAL FEATURES

FROM TECTONIC MAP OF THE UNITED STATES (A.A.P.G., 1962) WITH ADDITIONS

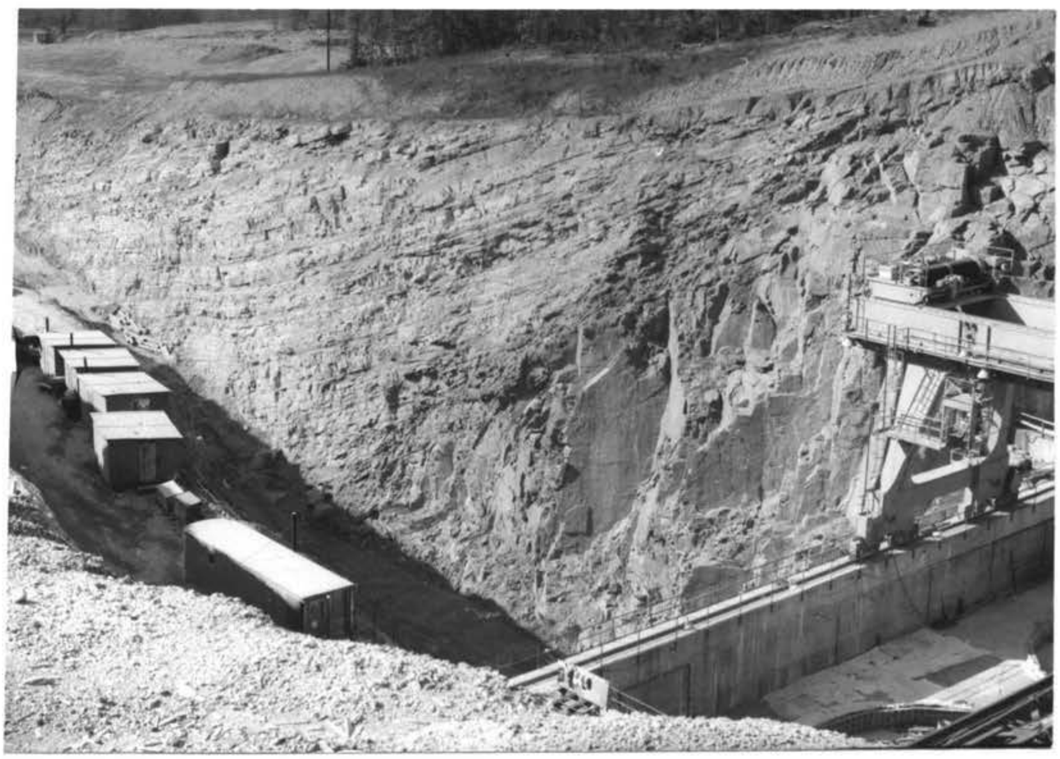


Figure 5. North wall of Union Electric Company Taum Sauk Cut. Sediments of the Davis Formation increase markedly in angle of dip and show moderate thinning adjacent to a rhyolite porphyry knob (right foreground).

Figure 6. Previously unmapped granite porphyry knob, Taum Sauk area. Dake (1930, p. 188) suspected the presence of this knob because of anomalously high contacts in the area.

Figure 7. Lamotte Formation outcrop west of Missouri Highway 21, and immediately south of Big River, Caledonia area. The formation is thin-bedded and dolomitic at this location.

Figure 8. Silty and conglomeratic dolomite within the upper portion of the Davis Formation, exposed adjacent to Missouri Highway M, Taum Sauk Area. This rock contains angular felsite fragments that are locally derived.

Figure 9. Typical quartz exposure, Potosi Formation, at the southeast margin of Little Pilot Knob. (SE¼, SW¼, Sec. 31, T. 38 N., R. 1 E.)

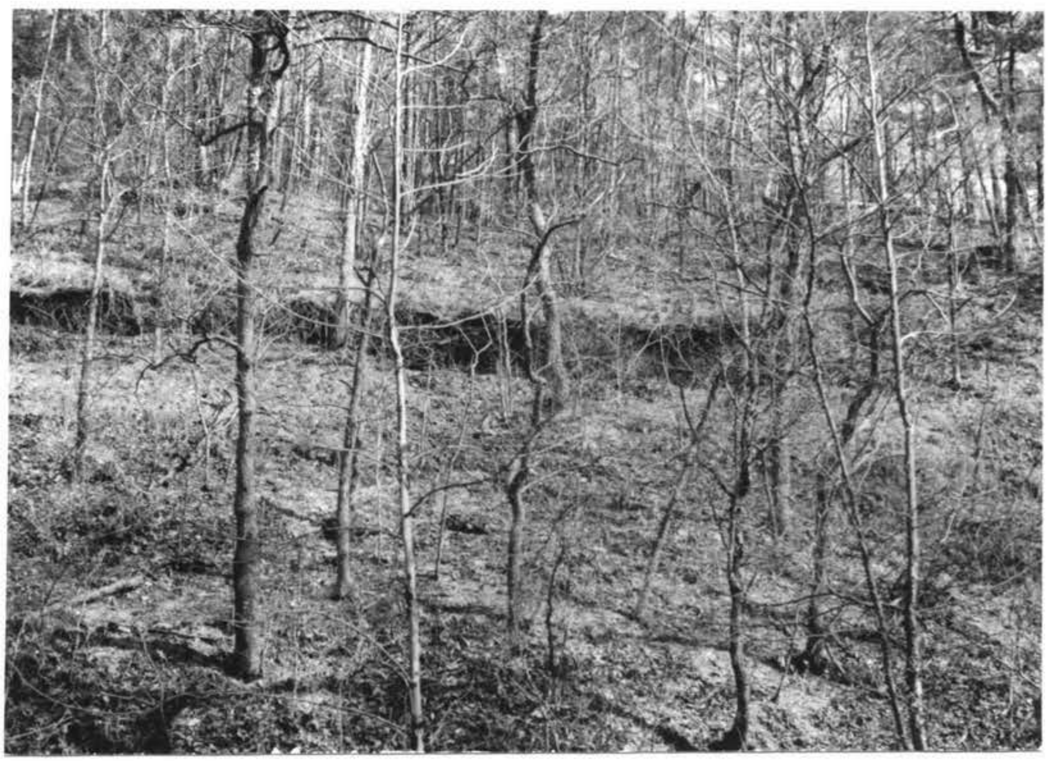


Figure 10. Projecting ledge of Cryptozoon reef structure within the Gasconade Formation immediately south of Little Pilot Knob. (SW¼, SW¼, Sec. 31, T. 38 N., R. 1 E.)

areal extent of these volcanic extrusives is unknown. They assign Precambrian rocks of Shannon County and an area northwest of the St. Francois Mountains to this early extrusive sequence. Following these extrusions a period of erosion is postulated.

The extrusion of a sequence of younger felsites is the next identified event. These younger felsites have a larger total outcrop area than the older sequence, but appear to have a lesser total volume (Snyder and Wagner, 1961, p. 90). The Stouts Creek rhyolite, which outcrops east of Ironton, Missouri, is assigned to this younger sequence.

Folding and faulting on an approximate north-south axis is indicated after the second period of felsite extrusions. Evidence for this orogenic episode is visible in surface outcrops and drill cores where steeply dipping flow structures assumed to be related to bedding are observed, and through underground mapping. A large number of the faults known in the Paleozoic sedimentary section within southeastern Missouri may have had their origin at this time. Numerous recurrent movements are indicated.

Intrusion of the granites of the Ozark Uplift is believed by Snyder and Wagner (1961, p. 91) to have closely followed the episode of orogenic movement. A large composite pluton is identified within the central part of the uplift. Only the uppermost portions of this pluton appears to have been exposed by erosion. A number of other granitic types have been identified in smaller exposures in other areas of the uplift. These may indicate other phases of the intrusive episode.

Radiometric age determinations on some of the younger intrusive granites of the Central Ozarks give ranges of 1.40 to 1.45 billion years (Hayes, 1961, p. 10).

Basic intrusions into the granitic bodies and the older extrusive units later developed.

A long period of erosion initiated in late Precambrian time persisted until the beginning of Upper Cambrian deposition. Regional tilting to the southwest and intermittent faulting occurred during this period of erosion. Sufficient upward tilting occurred within the Ozark Plateau to result in eroding and exposure of the large central granite pluton (Snyder and Wagner, 1961, p. 93). Lamotte Formation deposition occurred directly upon the exposed granite surface in many places within the Central Ozarks.

Paleozoic Structural History

Post-Lamotte Regional Tilting. Snyder and Wagner (1961) present calculations on regional tilting based upon present elevations of the Lamotte Formation. On the assumption that the Lamotte Formation, as originally deposited, represented an essentially horizontal sedimentary unit, they reason that any differences in elevation now observed can be attributed primarily to subsequent regional tilting. The top of the Lamotte Formation is at 900 feet above sea level near Knoblick Mountain south of Farmington, Missouri; farther southeast near Taum Sauk Mountain the upper surface of the Lamotte is at 400 feet above sea level. At Stegall Mountain in Shannon County, a distance of approximately sixty five miles to the southwest from Knoblick Mountain, the Lamotte Formation contact is encountered in drilling at 800 feet below sea level. Snyder and Wagner conclude that these differences in elevation indicate a regional tilting to the southwest of some 1,700 feet, and believe that the Shannon County peaks stood higher in Late Cambrian time than the present St.

Francois Mountains.

A possible objection to this evidence of regional tilting is the geologic probability that the Lamotte Formation was deposited during marine transgression on a gently sloping erosion surface. An average dip to the southeast of the Precambrian erosion surface of one-half degree would produce a difference in elevation of 3,055 feet within a distance of sixty five miles. In a normal marine transgression, the Lamotte Formation environment would be expected to migrate toward the northwest, gradually rising in elevation, followed and finally covered by limestone of the shallow marine neritic environment.

Stratigraphic Evidence of Paleozoic Structural History. The structural history of the Ozark Uplift during the Paleozoic, Mesozoic, and Cenozoic Eras is a problem on which only limited evidence is available. Stratigraphic features within the uplift offer at least partial evidence of its structural history. The complete absence of Permian and younger marine sediments within the uplift area indicate that the Ozarks have remained above sea level since Pennsylvanian time. During this long period of emergence, the uplift was subjected to erosional forces which removed a large but unknown thickness of sediments.

Isolated outliers of Devonian, Mississippian, and Pennsylvanian sediments lying on Lower Ordovician and Upper Cambrian rocks offer evidence of repeated submergence of at least portions of the uplift during the Middle and Later Paleozoic. No Silurian sediments have been identified within the Central Ozarks. The unconformities which separate these younger sediments from the older underlying rocks indicate that the uplift was subjected to long periods of subaerial erosion during this time. These repeated submergences are not necessarily attributable to repeated downwarp and uplift, but could be explained as well by eustatic changes in sea level. Both eustatic changes in sea level and structural uplift may have been involved.

Earlier workers have postulated several important unconformities in the Upper Cambrian and Lower Ordovician section within the Central Ozarks. In the local areas studied no evidence was observed to confirm these unconformities. In the Taum Sauk area, where an unconformity had been previously postulated, it was found that a normal stratigraphic sequence existed.

By use of insoluble residue studies, the Missouri Geological Survey has been able to identify a number of important unconformities within the Upper Paleozoic section of Missouri. Yet, Mary McCracken of the Missouri Geological Survey indicates that no insoluble residue evidence has been recognized for important unconformities between the top of the Canadian Series and the base of the Cambrian in the Central Ozarks region (M. McCraken, oral communication, 1963).

The writer concludes that the area of the Central Ozarks underwent no important submergence-emergence cycles during Late Cambrian and Early Ordovician time. Rather, it appears that the Central Ozarks were more or less continuously submerged under shallow epicontinental seas during this time. These seas underwent limited transgressions and regressions, as is evidenced by an abundance of mud cracks, edgewise conglomerates, and ripple marks.

Structural Features of the Ozark Uplift

The structural center of the Ozark Uplift lies within the St.

Francois Mountains of the Central Ozarks. Here, as previously noted, rhyolite porphyry of Taum Sauk Mountain rises to 1,772 feet above sea level. Important structural features associated with the uplift are the Farmington Anticline, the Ste. Genevieve Fault Zone, the Palmer Fault zone, and the Simms Mountain-Mine Lamotte Fault Zone, all of which are located north and northeast of the central portion of the uplift. Figure 4 is a generalized structure map which shows the locations of these features.

Farmington Anticline. A broad anticline lies immediately east of the Lead Belt in western Ste. Genevieve County, Missouri. Uplifted Lamotte Sandstone is exposed in a broad area in the core of the anticline. Several exposures of the underlying Precambrian granite occur near its crest. The anticline strikes approximately N. 30°W., and extends from French Village, Missouri, to Avon, Missouri, a distance of more than twenty miles. The structure broadens toward the south, and attains a maximum width of more than twelve miles immediately east of Farmington, Missouri.

The age of the Farmington Anticline is uncertain. Weller and St. Clair (1928, p. 258) believe it was formed during Bonneterre time and remained a positive area until the beginning of Potosi deposition. In support of this, they cite the difference in thickness and lithology of the upper Bonneterre, Davis, and Derby-Doerun Formations on the two sides of the anticline. They attribute this difference to varying rates of deposition on opposite sides of the anticline, which acted as a barrier. Kidwell (1947, p. 12) believes the structure to be contemporaneous with the large fault zones which lie closely adjacent to it.

Ste. Genevieve Fault Zone. A fault zone, termed the Ste. Genevieve, lies along the northeastern margin of the Ozark Uplift. It extends from near St. Clair, Missouri, southeastward for more than one hundred miles, and crosses the Mississippi River into Illinois at a point north of Grand Tower, Illinois. This fault zone consists of a large number of generally parallel northwest trending fractures. At several places large graben blocks occur within the zone. Kidwell (1947, p. 12) assigns a maximum of 1,200 feet vertical displacement to this fault zone in portions of Ste. Genevieve County. Downthrow is to the northeast, with the exception of a few minor, possibly antithetic faults which have downthrow to the southwest. All of the faults of this fault zone dip at high angles, and in places stand essentially vertical. Weller and St. Clair (1928, p. 258) indicate that maximum displacement in eastern Ste. Genevieve was achieved in Late Devonian time, when a throw of 1,000 feet was developed. Mississippian age rocks are displaced near the point where the fault zone crosses the Mississippi River, and Pennsylvanian sediments are faulted along the continuation of this fault in Illinois.

<u>Simms Mountain-Mine Lamotte Fault Zone.</u> A fault zone strikes approximately parallel to the Ste. Genevieve Fault Zone, some forty miles to the southwest. It extends from a few miles east of Fredericktown, Missouri, northwestward to the vicinity of Leadwood, Missouri, a distance of more than thirty miles. Kidwell (1947, p. 12) assigns an average throw of 500-600 feet to this fault zone. Again, as with the Ste. Genevieve Zone downthrow is to the northeast. Individual faults dip at a high angle and often are essentially vertical.

<u>Palmer Fault Zone.</u> A distinctive fault zone extends from the

vicinity of Bismarck, Missouri, in a westerly direction to the well-known Crooked Creek Structure, ten miles south of Steelville, Missouri. The total length of the Palmer Fault Zone is more than fifty miles. This third large fault zone is a complex series of fractures in a belt from two to five miles in width (Dake, 1930, p. 181). Dake (1930, p. 182) assigns a minimum displacement of 800 feet to the fault zone in an area north of Caledonia, Missouri. Downthrow is to the north and northeast and individual fault planes are nearly vertical.

The Ste. Genevieve, Simms Mountain-Mine Lamotte, and Palmer Fault Zones constitute the major fault systems of the Ozark Uplift. A number of smaller faults and fault zones have also been mapped in various areas in the Central Ozarks. One of the more important of these is the Big River Fault Zone. This strikes northeastward and connects the Ste. Genevieve Fault Zone and the Palmer Fault Zone. Kidwell (1947, p. 13) assigns a maximum of 120 feet of throw to this fault zone, with downthrown block to the northwest. The Big River Fault Zone forms the northern boundary of a structural block which James (1952, p. 652) has termed the Flat River Structural Block. Other small fault zones are the Berryman Fault Zone and the Shirley Fault Zone, located north of the Palmer Fault Zone, and the Black Fault Zone, situated along the southeast margin of the St. Francois Mountains. Again, as with previously discussed faults, these are essentially vertical in nature, and are classified as normal faults.

Summary of Paleozoic, Mesozoic, and Cenozoic Structural History

With exception of possible gentle regional tilting, the Ozark Uplift appears to have been a relatively stable area during the Lower

Paleozoic. Except for the higher peaks, the area was submerged under shallow seas which underwent numerous but limited transgressions and regressions. During this time the Central Ozarks area may have undergone regional tilting to the southwest. However, present evidence for regional tilting is supported only by elevations of the top of the Lamotte Formation. This unit may or may not have been originally horizontal.

In middle and later Paleozoic time, the Ozark Uplift seems to have become a gradually more pronounced positive area. With continued and possibly accelerated uplift and regional tilting to the southwest, stresses must have developed along the northeastern periphery of the uplift.

The northwest-trending fault zones along the northeast margin of the uplift may have formed in response to these stresses. It seems significant that all the major faults are essentially vertical, downthrown to the north and northeast, and that their aggregate displacement is roughly equivalent to the amount of regional tilting to the southwest postulated by Snyder and Wagner (1961, p. 93).

The age of faulting within these broad fault zones is uncertain. Dake (1930, p. 122) indicates that portions of the Palmer Fault Zone developed at the close of the Cambrian. Devonian and Mississippian formations are involved in portions of the Ste. Genevieve Fault Zone. Formations of Pennsylvanian age are involved along the continuation of the Ste. Genevieve Fault Zone in Illinois. It is probable that these faults could have formed early in Paleozoic time or even Precambrian and shown intermittent uplift, increasing in displacement through the Paleozoic. Intensity and magnitude of faulting may have reached a maximum in Late Paleozoic time when the Ozark Uplift appears to have reached a maximum elevation above sea level.

The Ozark Uplift has been continuously above sea level and subjected to erosion since Late Paleozoic time. Bridge (1930, pp. 149-150) postulates a peneplanation of the Central Ozarks region by late Tertiary time, and suggests that the level skyline of the Ozarks represents the remnant of this ancient peneplain. He indicates that the present Ozark drainage system is essentially identical to one which existed on the peneplain surface.

The entrenched meanders of the Central Ozarks today are attributed to the down-cutting of streams flowing on the Late Tertiary peneplain when the region underwent final uplifting in Late Tertiary and Recent time.

THE LITTLE PILOT KNOB AREA

INTRODUCTION

Little Pilot Knob is located in an area of the northern most exposed Precambrian knobs of the Central Ozarks. It lies on a northeast-trending ridge of exposed Precambrian igneous rock more than three miles long, and is the highest of three individual knobs within the area. The crest of Little Pilot Knob is 1,412 feet above sea level, and is one of the best exposed knobs of the north-central Ozarks.

This area was first considered for detailed study because of its location in the northern central Ozarks, and because the flanks of Little Pilot Knob are extensively exposed by erosion. Dake (1930, p. 188) suspected a buried Precambrian hill approximately 1.5 miles east of the crest of Little Pilot Knob, and the evidence he cited was considered to be deserving of more detailed study.

The Little Pilot Knob area was mapped geologically at a scale of 1:6000. This map was reduced to a 1:24000 scale for inclusion in this report (Figure 13). All observations of dips and joints within the area are plotted on the geologic map. A vertical intensity magnetic survey was completed by use of a Jalander flux-gate type magnetometer. The results of this survey are presented in Figure 11. The magnetic susceptibility of the Little Pilot Knob trachyte porphyry was determined in order to calculate the theoretical total magnetic field associated with the knob by use of the surface integral method. The results of the theoretical field calculations are presented in Chapter 10.

LOCATION, SIZE AND ACCESSIBILITY OF THE AREA

The Little Pilot Knob area is a rectangular area in the east-central part of Washington County, Missouri, in sections 29, 30, 31 and 32, T. 38 N., R. 1 E., and sections 25 and 36, T. 38 N., R. 1 W. A total area of six square miles is represented (Figure 13).

The area lies ten miles west of Potosi, Missouri, and five miles southwest from the St. Joseph Lead Company Indian Creek mine. The Missouri Conservation Commission Floyd Lookout Tower stands at the crest of Little Pilot Knob in the area.

The area can be reached by turning northward onto Missouri Route AA from Missouri State Highway 8 at Shirley, Missouri. The area is five miles north of Highway 8 at this point. It is also accessible by turning westward on Route AA from Missouri State Highway 155 one mile northwest from Potosi, Missouri. The area is eight miles from Highway 155 at this point. A secondary road leads into the area from Missouri Route AA near the Sunnen Lake Y.M.C.A. Camp. All roads in the area are in good condition and are useable throughout the year.

PREVIOUS WORK

The Little Pilot Knob area was previously mapped as part of a much larger area by C. L. Dake in 1929, at a scale of 1:62500. French (1956) completed a petrographic study of the Little Pilot Knob trachyte porphyry as part of a study of Precambrian rocks of Washingtn County. Gooding (1951) mapped the southwest portion of the Richwoods quadrangle, immediately north of the Little Pilot Knob area. No other geologic work has been published on the area.

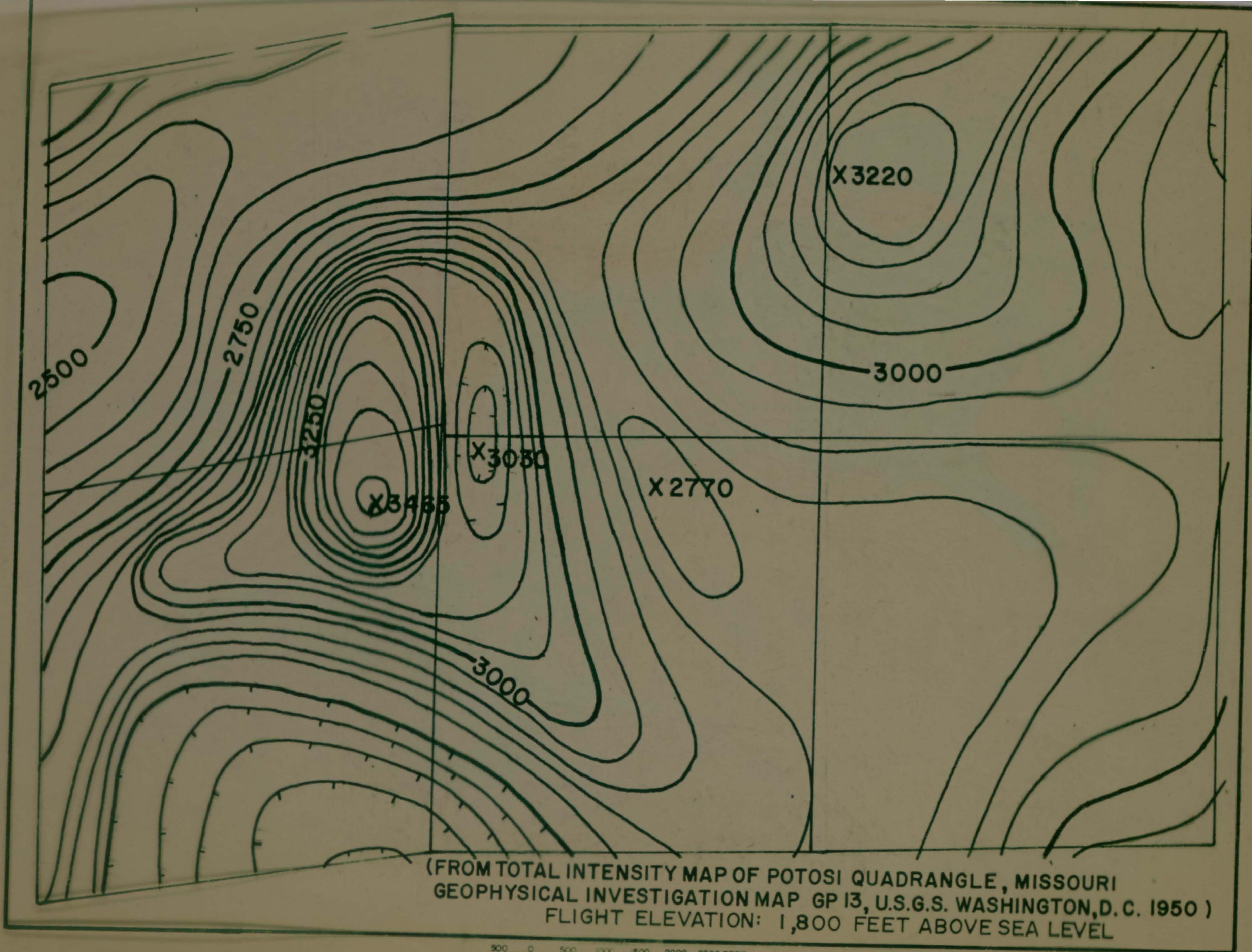
SURVEY COMPLETED JANUARY, 1963
JALANDER VERTICAL INTENSITY MAGNETOMETER NO. 57126
CALIBRATED SCALE VALUE 9.5 GAMMAS PER SCALE DIVISION
SURVEY ACCURACY ±5 GAMMAS

VERTICAL INTENSITY MAGNETIC SURVEY
LITTLE PILOT KNOB AREA
WASHINGTON COUNTY, MISSOURI

500 0 500 1000 1500 2000 2500 FEET

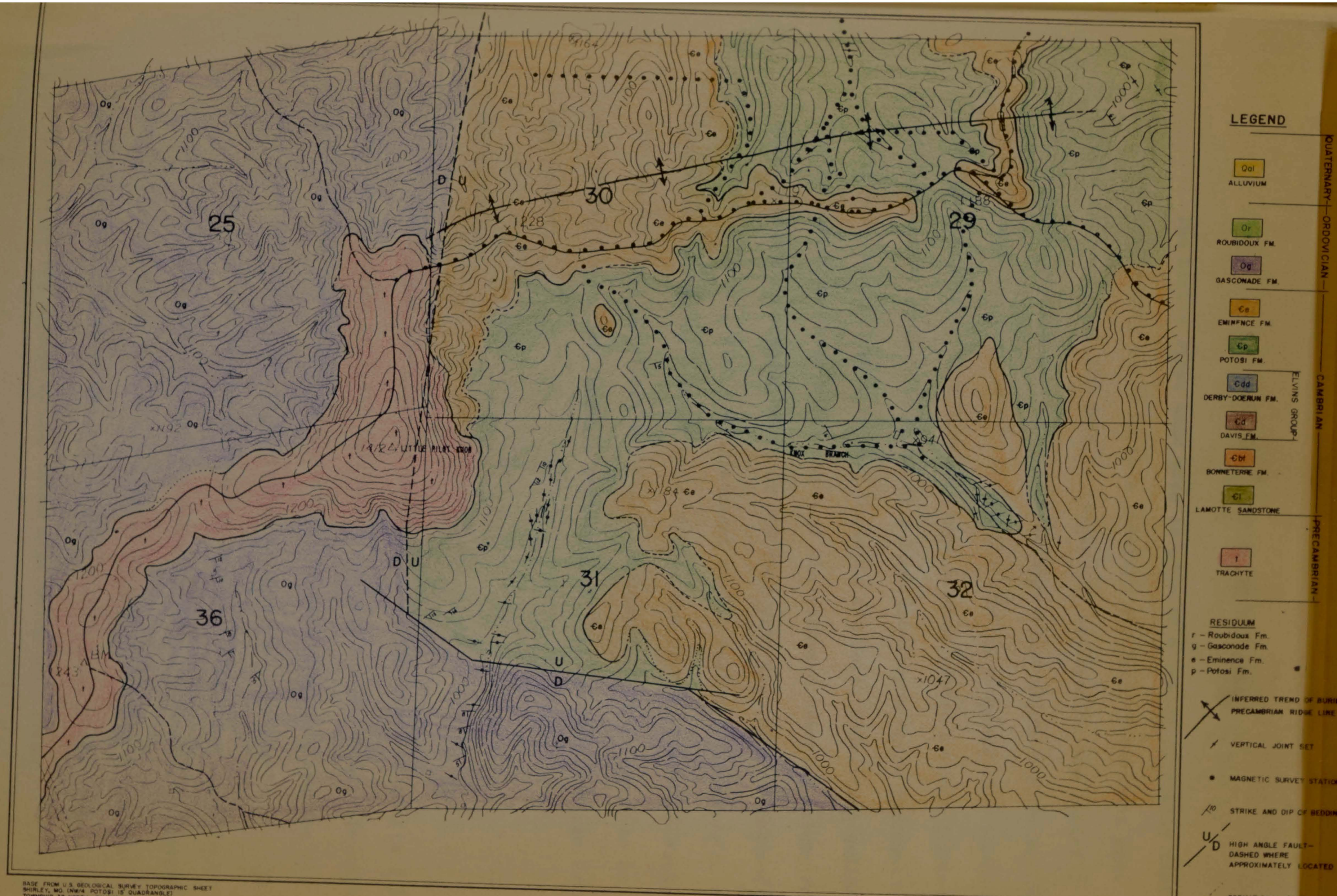
CONTOUR INTERVAL 100 GAMMAS
SURVEYED RELATIVE TO AN ARBITRARY DATUM

FIGURE 11



TOTAL INTENSITY AEROMAGNETIC MAP OF THE LITTLE PILOT KNOB AREA

FIGURE 12



GEOLOGIC MAP OF THE
LITTLE PILOT KNOB AREA
WASHINGTON COUNTY, MISSOURI

500 0 500 1000 1500 2000 2500 FEET

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

FIGURE 13

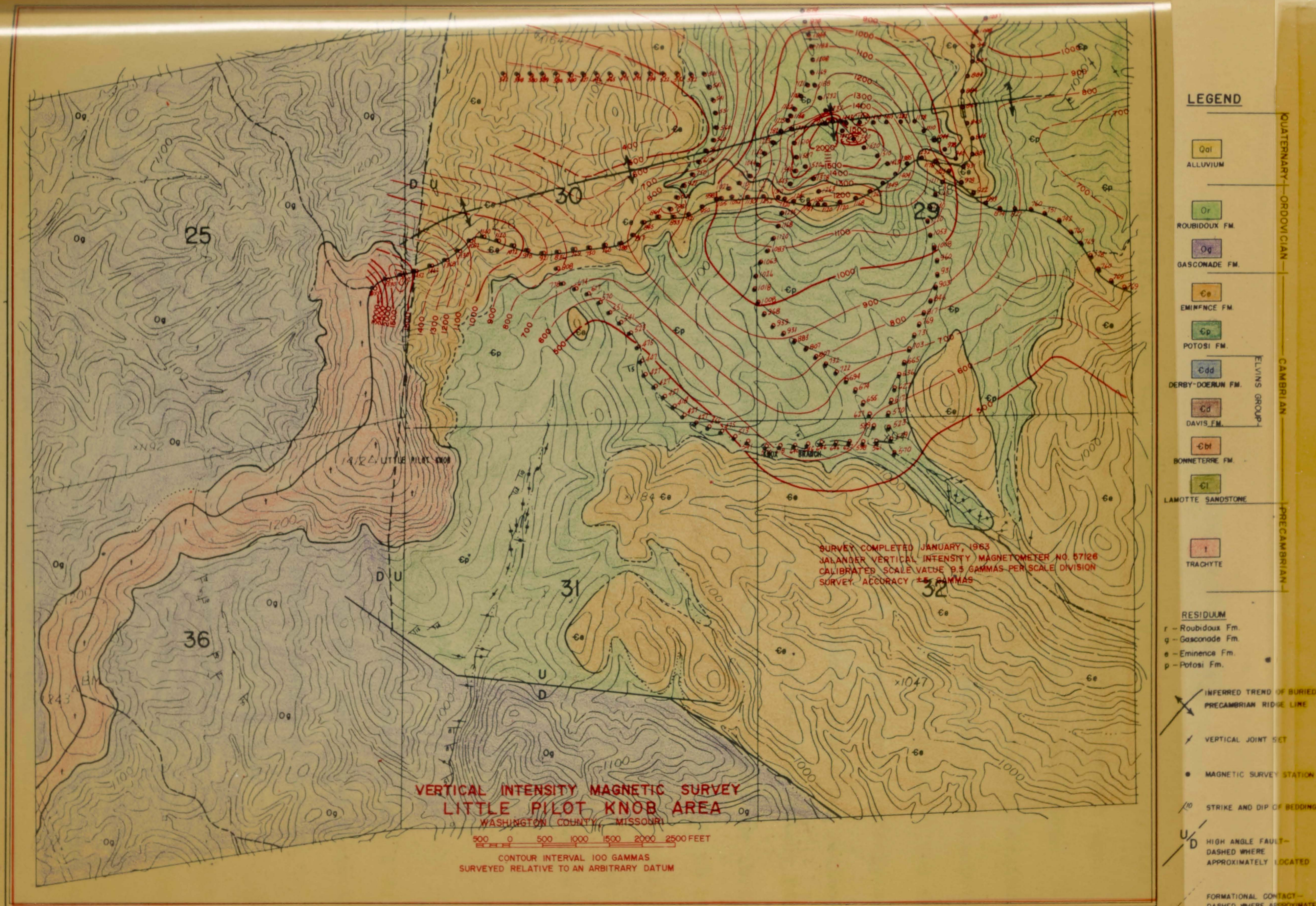
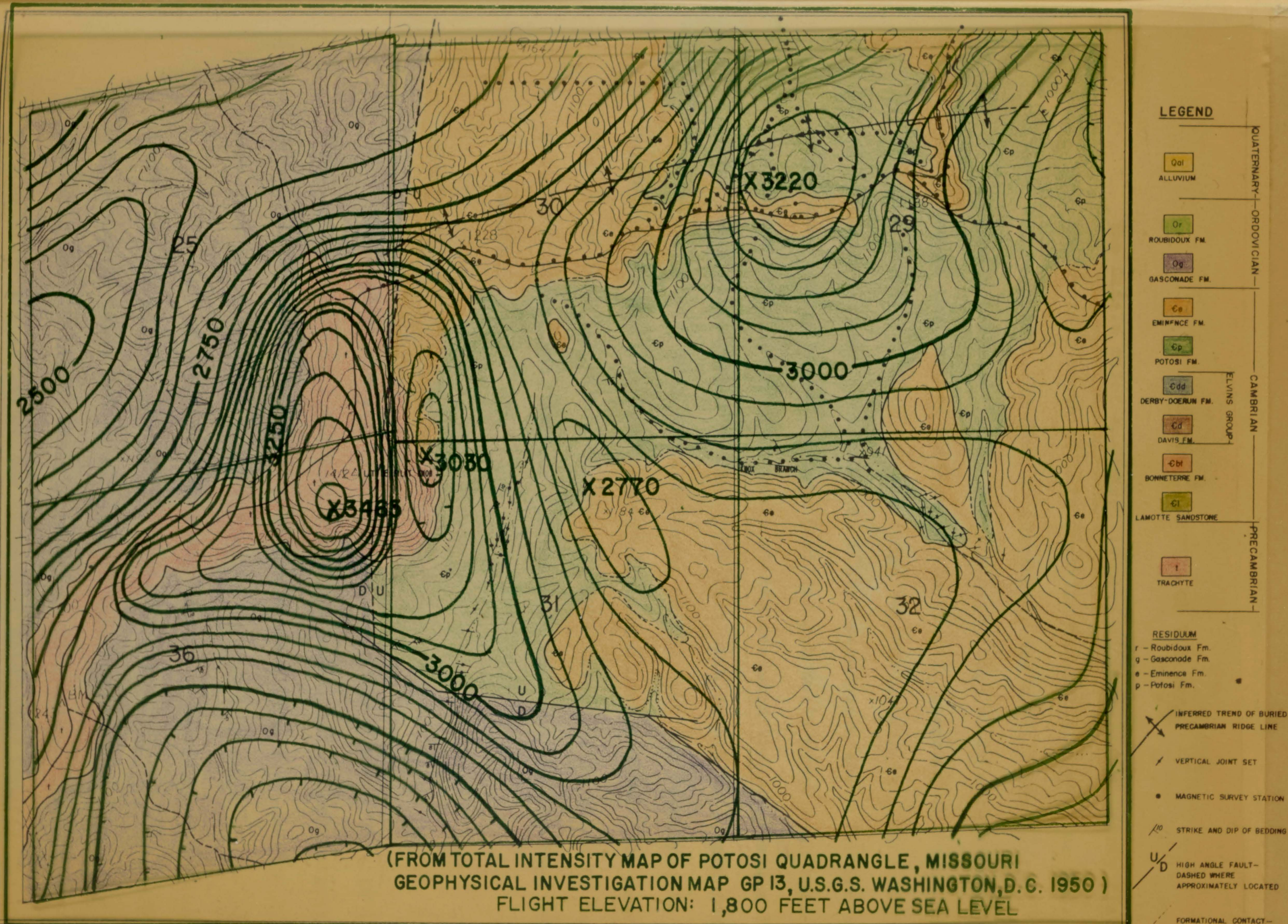


FIGURE 11

GEOLOGIC MAP OF THE
LITTLE PILOT KNOB AREA
WASHINGTON COUNTY, MISSOURI

500 0 500 1000 1500 2000 2500 FEET
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

FIGURE 13



(FROM TOTAL INTENSITY MAP OF POTOSI QUADRANGLE, MISSOURI
GEOPHYSICAL INVESTIGATION MAP GP 13, U.S.G.S. WASHINGTON, D.C. 1950)
FLIGHT ELEVATION: 1,800 FEET ABOVE SEA LEVEL

BASE FROM U.S. GEOLOGICAL SURVEY TOPOGRAPHIC SHEET SHIRLEY, MO. (NW/4 POTOSI 15' QUADRANGLE) TOWNSHIP 38 NORTH, RANGES 1 EAST & 1 WEST

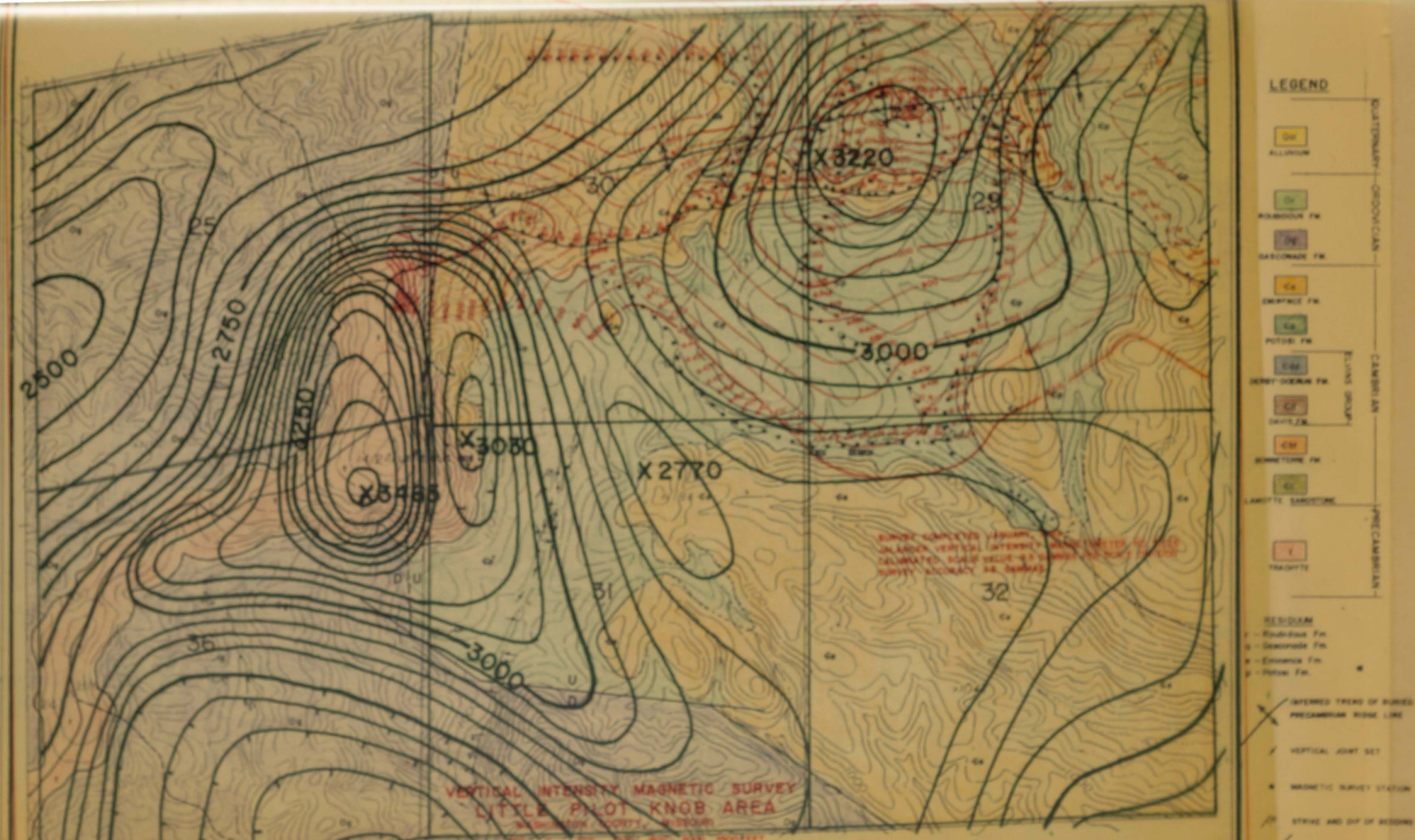
GEOLOGIC MAP OF THE LITTLE PILOT KNOB AREA WASHINGTON COUNTY, MISSOURI

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

TOTAL INTENSITY AEROMAGNETIC MAP OF THE LITTLE PILOT KNOB AREA

FIGURE 12

FIGURE 13



(FROM TOTAL INTENSITY MAP OF POTOSI QUADRANGLE, MISSOURI
GEOPHYSICAL INVESTIGATION MAP GP 13, U.S.G.S. WASHINGTON, D.C. 1950)
FLIGHT ELEVATION: 1,800 FEET ABOVE SEA LEVEL

FIGURE 11

TOTAL INTENSITY AEROMAGNETIC MAP OF THE LITTLE PILOT KNOB AREA

FIGURE 12

FIGURE 13

GEOLOGIC SETTING OF THE AREA

The Little Pilot Knob area is part of a region of nearly flat -lying sedimentary rocks of Late Cambrian and Early Ordovician age. These approximate 1,200 feet in thickness, and overlie the buried Precambrian erosion surface. A large high ridge which extends southwestward through the western portion of the area is composed of Precambrian trachyte porphyry. This igneous ridge extends upward through 1,200 feet of sedimentary rocks. It stood as a high prominence above Precambrian topography before burial by Late Cambrian and Early Ordovician sediments. The knob area is seven miles north of the eastward trending Palmer Fault, which has a displacement of about 800 feet with downthrow to the north. The Shirley Fault, with a displacement of 200 feet and downthrow to the southwest, is the only fault known within the Little Pilot Knob area. The age of faulting within the area is uncertain, but is known to be post-Early Ordovician, because sediments of this age are involved in the displacement.

Geomorphology

The highest elevation in the area is at the crest of Little Pilot Knob, which stands at 1,412 feet above sea level. The lowest elevation, in the stream bed of Knox Branch at the eastern margin of section 32, is less than 880 feet. The total relief is more than 530 feet.

The high southwestward trending igneous ridge forms a drainage divide, with small intermittent tributaries draining generally northward and southward. Knox Branch and a small intermittent stream flowing southward east of Little Pilot Knob may be structurally controlled, as they parallel the strike of the rocks over which they flow.

The ridge on which Little Pilot Knob is located has the steepest slopes and greatest relief of the area due to the extreme resistance of the underlying igneous rock to weathering.

The westernmost portion of the area, underlain entirely by the Gasconade Formation, is an area of steep bluffs and narrow gulleys, and well displays the cliff-forming characteristics of the Gasconade Formation. Much of sections 31 and 32 is underlain by the Eminence Formation. This formation develops only moderately steep bluffs. In general, areas underlain by the Eminence Formation have more subdued topography than that of the Gasconade Formation.

The broad open area extending through the northwestern portion of section 31 and through the south halves of sections 29 and 30 is underlain by the Potosi Formation. This formation in the Little Pilot Knob area has shallow slopes and in general, very subdued topography.

An excellent example of topographic expression of the Shirley Fault is seen within the southwest quarter of section 31, where the fault crosses the small intermittent stream flowing toward the south. The formations involved are Eminence and Potosi to the north of the fault, and the Gasconade Formation to the south. Here, the steep bluffs of the Gasconade Formation pass into a broad open area of relatively low slopes which is underlain by Potosi and Eminence dolomite.

STRATIGRAPHY OF EXPOSED FORMATIONS

Rock formations cropping out within the Little Pilot Knob area are both igneous and sedimentary and include four mappable units. Igneous rocks crop out along the high ridge which extends through the western one third of the area. The sedimentary rocks consist almost entirely of dolomite with associated chert and quartz druse. In a number of areas sandstone residuum of the Robuidoux Formation is present.

Trachyte Porphyry

The large high ridge in the western portion of the area is entirely underlain by Precambrian trachyte porphyry. French (1956, pp. 62-69) discusses this rock in his work. Megascopically the rock has a fine-grained to aphanitic, black to dark gray groundmass, with enclosed phenocrysts of greenish brown hornblende and pale greenish white and pink feldspar. The phenocrysts range from ½ mm. to 3 mm. Carlsbad twinning is apparent on some of the pale greenish feldspar phenocrysts. No quartz is visible. French (1956, p. 63) presents a chemical analysis of the Little Pilot Knob trachyte porphyry, and discusses the varying crystalline phases of this rock in detail.

The Little Pilot Knob trachyte porphyry differs from igneous rocks of other areas studied in that its weathered surfaces are much more rounded, and the rock appears to be less jointed. Weathered trachyte porphyry float is almost invariably composed of pitted, well-rounded cobbles. The pitted aspect is due to differential weathering of the phenocrysts in relation to the aphanitic ground mass. No megascopic flow structures were observed in the rock.

Potosi Formation

The upper half of the Potosi Formation, approximately 150 feet, crops out at a large number of localities within sections 29 and 30, and in the western portion of section 31. The Potosi Formation is similar in lithology to the overlying Eminence Formation. Distinguishing characteristics of the formation are the abundance of large well-developed quartz druses, light brown color, medium to finely crystalline texture, and massive beds with a general absence of bedding planes. Within the Little Pilot Knob area a few thin finely crystalline, light brown dolomite beds occur within the lower portion of the Eminence Formation. These beds lack quartz druses typical of the Potosi Formation.

For field mapping, the Eminence-Potosi contact was selected at an elevation about twenty feet higher than the highest observed Potosi druse float at a given locality. This approach results in a fairly accurate location of the contact, since the druse float is easily recognized, and is abundant wherever the Potosi Formation crops out in the area.

Eminence Formation

The Eminence Formation crops out within the north half of section 30, and in the southern portions of sections 31 and 32. Only the lower half of the formation is present within the Little Pilot Knob area. Distinguishing characteristics of the Eminence Formation are medium to coarsely crystalline texture, light gray color, massive beds with a lack of bedding planes, and general scarcity or absence of druse so abundantly developed in the underlying Potosi Formation.

Gasconade Formation

The Gasconade Formation is present within the western one-third of the area in sections 25, 36, and in the southwest quarter of section 31. Some of the most distinguishing characteristics of the Gasconade Formation are the great abundance of dull white chert, steep bluffs and protruding ledges, *Cryptozoon* reef material, and undulating lenticular bedding.

The basal Gunter Sandstone Member of the Gasconade Formation was not observed in outcrop within the Little Pilot Knob area.

Good exposures of the Gasconade Formation occur within the southwest quarter of section 31 in a steep bluff immediately south of the Shirley Fault. Over a large portion of the area, no Gasconade outcrops were observed, but the great abundance of typical Gasconade chert is evidence for the formation.

Roubidoux Formation

Except for a few scattered residual deposits, the Roubidoux Formation is not present within the Little Pilot Knob area. At the crest of several higher hills where the Gasconade Formation occurs in outcrop, fragments and blocks of highly weathered sandstone, and a very sandy soil are evidence of the former presence of the Roubidoux Formation. These areas are indicated as residuum rather than actual outcrops on the geologic map.

No consolidated sedimentary units younger than the Roubidoux Formation were observed within the area.

Quaternary Surficial Deposits

Streams within the Little Pilot Knob area for the most, flow on bedrock. Where alluvium and rock debris are present, the deposits form a thin veneer of very transient nature.

DEPOSITIONAL ENVIRONMENT OF THE LITTLE PILOT KNOB AREA

Outcrops of sedimentary rocks of the Potosi, Eminence, and Gasconade formations were observed at a large number of localities. These outcrops were located as near as 300 feet to the exposed igneous knob, and as far removed as one and one-half miles. The outcrops were examined for such evidence of depositional environment as lithology, detrital igneous materials, ripple marks, cross-bedding, stratification lines, mud cracks,

Figure 14. Conjugate joint system in bed of small intermittent stream immediately east of Little Pilot Knob. The joints trend northward, and a single joint in the foreground trends eastward (SE¼ NW¼ sec. 31, T. 38 N., R. 1 E.).

Figure 15. Strong eastward trending joints within the Gasconade Formation in the bed of small intermittent stream to the south of Little Pilot Knob. (SW¼ SW¼ sec. 31, T. 38 N., R. 1 E.).

Figure 16. Shirley fault zone, immediately south from Little Pilot Knob. Gasconade Formation at left, with Eminence Formation to the right. (NW¼ SW¼ sec. 31, T. 38 N., R. 1 E.)

reef structure, slump structure, brecciated zones, and contained fossils.

Such evidence proved extremely scarce. Units of the Potosi and Eminence formations within the area are completely dolomitized. Bedding planes and even lines of stratification are rare.

No detrital igneous material was observed in any of the sedimentary units. In the center of the northeast quarter of section 36 an abundance of green clay-like material, probably glauconitic clay, was observed at an outcrop of the Potosi Formation. This outcrop, within 300 feet of an igneous exposure, is directly south of the crest of Little Pilot Knob, and some 200 feet lower in elevation. This material may have formed as an alteration product of pre-existing feldspar or other minerals. None of the postulated pre-existing minerals was observed at the outcrop.

A horizon of Cryptozoon reef structure is present within the upper portion of the Gasconade Formation where it outcrops in a bluff 4,000 feet southwest, and two hundred feet below the crest of Little Pilot Knob. Rocks at this outcrop dip at 5 degrees toward the southwest. This reef outcrop appears identical to others observed throughout the Central Ozarks.

At a few localities stratification lines were suggested by thin dark gray color banding within otherwise massively bedded dolomite. These lines were entirely regular, giving no indication of cross-bedding, ripple marks, or slumping.

No fossils were seen at outcrops in the Little Pilot Knob area. However, numerous fragments of silicified gastropods were found in residual cherts in the area.

Sedimentary rocks outcrops in the Little Pilot Knob area appear essentially identical to those of equivalent age throughout the region. This general uniformity with formations known elsewhere suggests that the ridge line of Little Pilot Knob had little influence upon surrounding sediments during Upper Potosi, Eminence, and Gasconade time.

STRUCTURE OF THE AREA

The high steep ridge on which Little Pilot Knob is situated was carved by sub-aerial erosion of the Precambrian surface during Precambrian and Early Cambrian time. Sedimentary rocks of Late Cambrian and Early Ordovician age display peripheral dips, faulting, and joints which formed subsequent to burial of the Precambrian ridge.

Peripheral Dips

The flanks of the presently exposed Precambrian ridge slope at angles ranging from 5 degrees to a maximum of 11 degrees. Based upon a Precambrian topography map prepared by French (1958) from drill hole data supplied by the St. Joseph Lead Company, the buried flanks of the Precambrian ridge slope much more steeply. These range from 23 degrees to a maximum of 40 degrees.

Sedimentary rocks overlying these steeply sloping flanks strike approximately parallel to the flanks of the Precambrian ridge, and dip from the ridge. Dake and Bridge (1929, pp. 151-168) term these "peripheral dips".

The highest dip observed in the Little Pilot Knob area is at a location immediately south of the knob in units of the Gasconade Formation. Here units dip at 15 degrees in a S. 40°E. direction, and strike generally parallel to the buried flanks of Little Pilot Knob. The Precambrian surface here slopes at 40 degrees, according to French (1956).

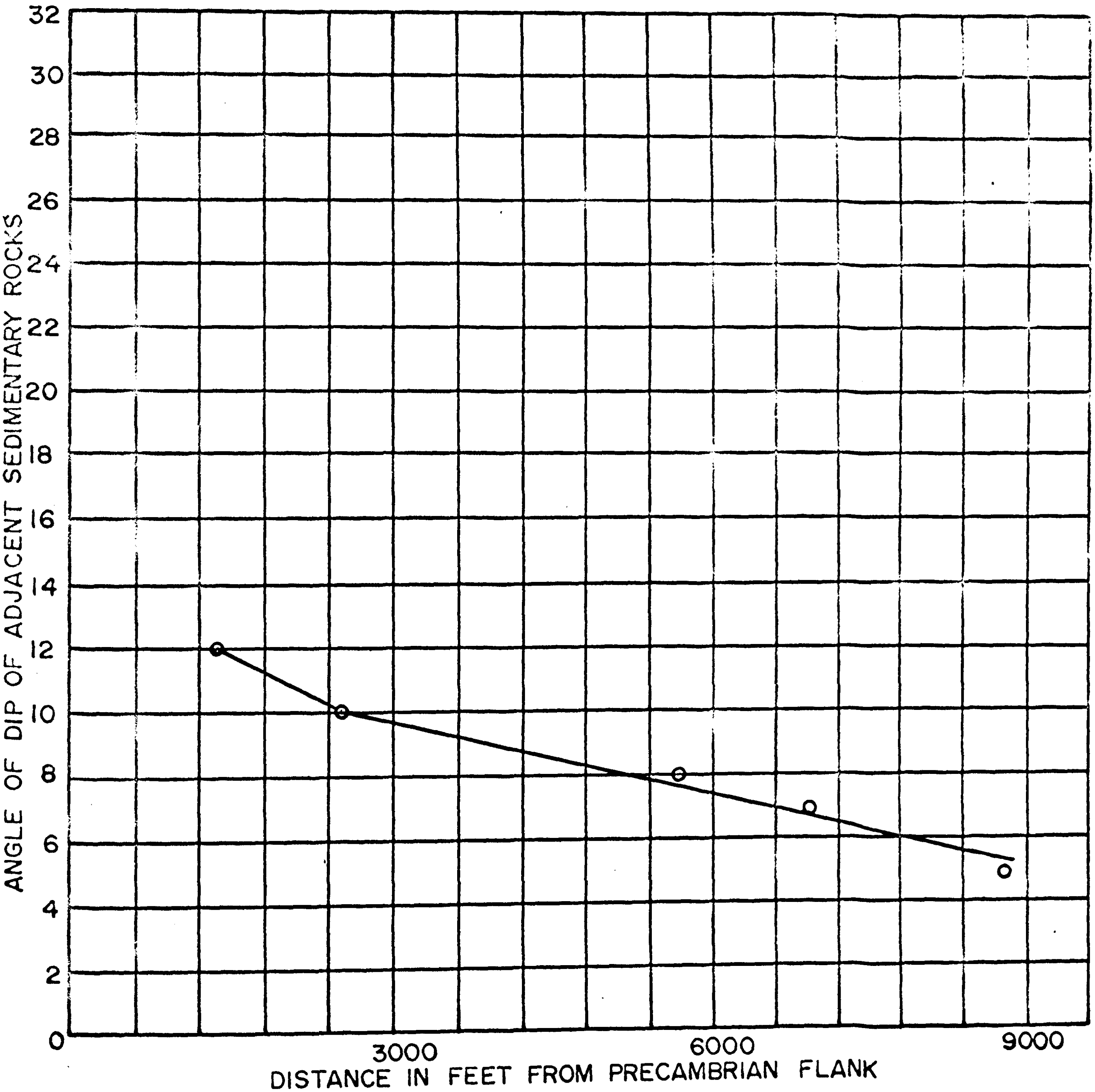


FIGURE 17. DECREASE IN ANGLE OF DIP WITH INCREASING DISTANCE FROM EXPOSED PRECAMBRIAN FLANK—SOUTHWEST FLANK OF LITTLE PILOT KNOB.

Units of the Potosi Formation dip at 12 degrees along the southeast margin of Little Pilot Knob. Here French (1956) shows the Precambrian surface to be sloping at 34 degrees, and again with strike generally paralleling that of the overlying sedimentary rocks.

Dips ranging from 5 degrees to 12 degrees were observed at other localities at the south and southeast flank of Little Pilot Knob. In every case their strikes approximately parallel the strike of the Precambrian ridge line.

The relatively high dips described above are present in rock units closely adjacent to the ridge line of Little Pilot Knob. These dips were observed to decrease in angle relatively rapidly with increasing distance from the exposed ridge line. Rocks of the Eminence Formation are essentially flat-lying one mile southeast of the crest of Little Pilot Knob.

Joint Patterns

More than 150 joints were mapped in the Little Pilot Knob area, but observations were restricted primarily to two locations. All joints observed are vertical in nature. Nearly all are located in stream beds where erosion has produced good exposures of bedrock.

The bedrock in a south-flowing intermittent stream immediately east and southeast from Little Pilot Knob is extensively jointed. The results of detailed mapping of these joints is shown in Figure 18.

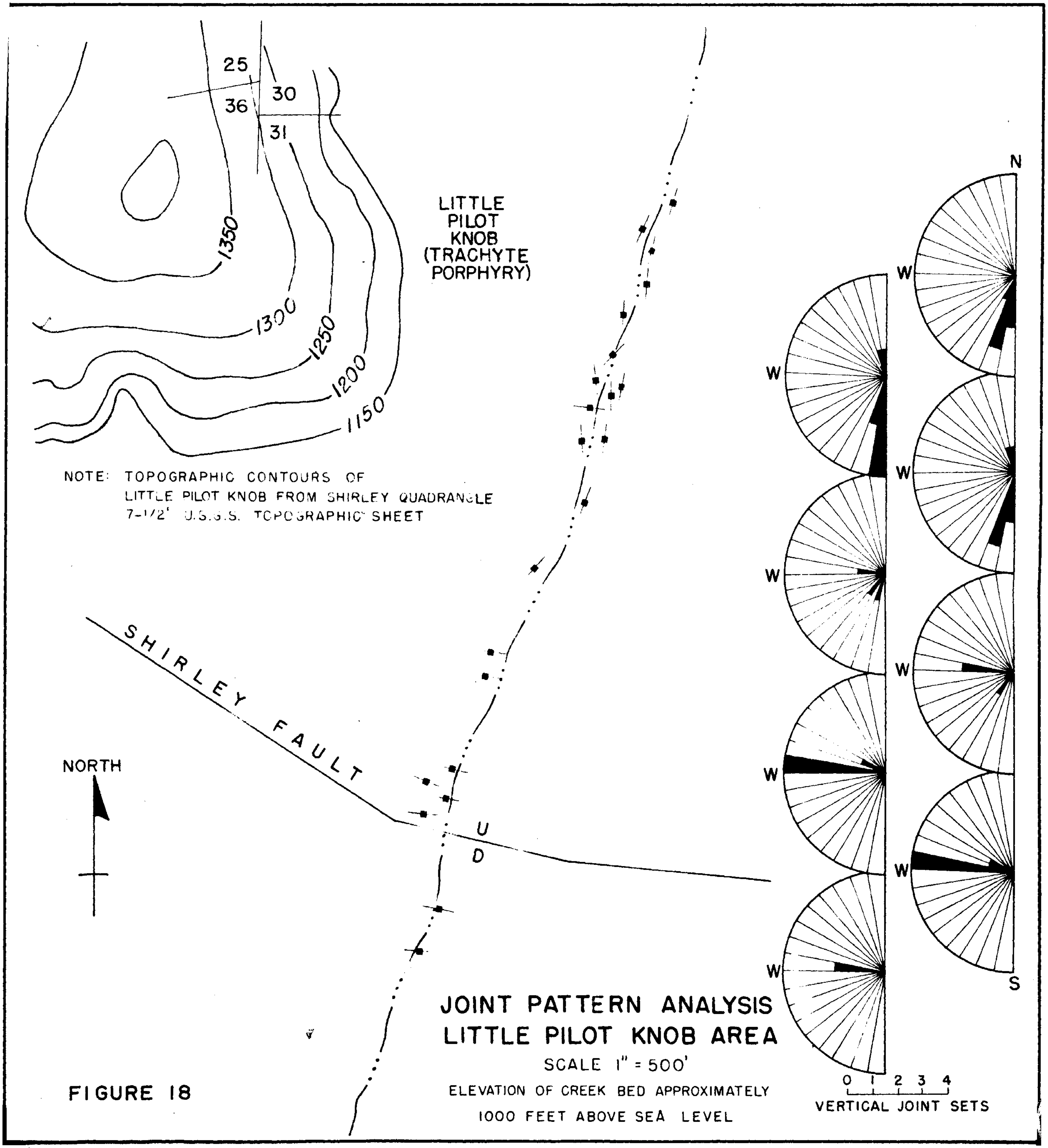
This figure shows the surface topographic contours of Little Pilot Knob, the southward flowing intermittent stream, and the position of individual joint sets within the stream. Each joint set represents approximately three vertical joints. Only the clearly defined joints were mapped. Vague lineations within the rock which might be termed "questionable joints" were not mapped.

In order to analyze and show graphically the relationship of the observed joints to the configuration of Little Pilot Knob, strike diagrams were prepared as shown along the right margin of Figure 18. Each semi-circular strike diagram stands opposite the interval of the intermittent stream for which the diagram is prepared, and includes only the joints within this interval. Each diagram overlaps by 50 percent each adjacent diagram. Thus, by following successively the diagrams, the reader can readily note the number of joints in a particular stream interval, their predominant strikes, and gross changes in strike along the stream.

Beginning with the uppermost three strike diagrams, it is seen that the joints in these intervals of the stream are relatively abundant, and strike entirely within 20 degrees east or west of north. The closely adjacent flank of the ridge line of Little Pilot Knob strikes northward in these intervals. The fourth and fifth diagrams from the top indicate west and southwest joint strikes, although fewer joints are present in these intervals. The flank of the ridge line of Little Pilot Knob here changes in strike from south to east.

The lowermost three strike diagrams show that more joints are present in these intervals, and strike is almost entirely within 10 degrees of west. These joints may be in part influenced by the Shirley fault.

Joints along the east flank of the ridge of Little Pilot Knob strike generally northward, parallel to the strike of the ridge line. At the southern margin of Little Pilot Knob, joints strike generally eastward, again parallel to the ridge line of Little Pilot Knob. A single joint



JOINT PATTERN ANALYSIS
LITTLE PILOT KNOB AREA

SCALE 1" = 500'

ELEVATION OF CREEK BED APPROXIMATELY
1000 FEET ABOVE SEA LEVEL

FIGURE 18

set of about four parallel joints, near the southeast margin of Little Pilot Knob, strikes nearly eastward or perpendicular to the ridge line of Little Pilot Knob. Figure 18 shows joints at this locality.

A second locality where numerous joints were observed was in the northwest quarter of section 32. Here, more than forty individual joints are present within a 1,500 foot interval along Knox Branch. About half the joints at this location strike generally northeastward. The remainder strike within a few degrees east or west of north.

Individual joints were observed at a few other scattered localities, as shown in Figure 13, the geologic map of the area. Although some additional joints are certainly present, very poor and limited exposures of bedrock over large portions of the area preclude the possibility of mapping them.

Elevations of Sedimentary Rock Contacts

Because of the high prominences formed by buried Precambrian hills, the adjacent and immediately overlying sedimentary units rise in elevation in the vicinity of such hills. Dake (1930) recognized this important principle and made extensive use of it in mapping the Edgehill and Potosi quadrangles.

In the area immediately to the east of Little Pilot Knob, but included in the Little Pilot Knob area, no exposures of Precambrian rock are present. However, Dake (1930, p. 188) reports unusually high Eminence-Potosi contacts in this area, and suspects the presence of a buried hill.

During the mapping of this area, it was found that the Eminence-

Potosi contacts are even higher than reported by Dake. This contact occurs at an elevation of 1,160 feet above sea level near the center of section 29, and falls to lower elevations in all directions from this point. The normal or usual elevation of the Eminence-Potosi contact along the northern margin of the Potosi quadrangle is about 900 feet. Accordingly, the contact in section 29 stands 260 feet higher than normal for the area. This contact rises rather abruptly, as it stands at 1,000 feet, or 160 feet lower immediately to the south in section 32.

Faulting

The Shirley Fault was mapped by Dake (1930) in the Little Pilot Knob area. He shows it reaching the southern flank of Little Pilot Knob where it is terminated. At this point directly south of Little Pilot Knob, the fault has more than 200 feet of vertical displacement. The writer examined this fault in detail in order to determine possible bearing upon the present study.

During preliminary reconnaissance, it appeared that the fault did not terminate, but extended toward the northwest with the high prominence of Little Pilot Knob standing upthrown. Mapping of the area northwest of Little Pilot Knob revealed only the presence of the Gasconade Formation. Since Eminence or Potosi rocks should be present if the fault continued into this area, it became evident that the fault does not pass to the west of Little Pilot Knob.

In mapping along the northeastern periphery of Little Pilot Knob it was found that the occurrence of the Gasconade Formation and the Eminence Formation was separated along a fairly distinct line, rather than the two units gradually occurring together in an area with the Eminence gradually rising toward the east.

This rather sharp line of separation between areal occurrence of the Gasconade and Eminence formations trended generally northeastward in the area. In mapping the southeastern portion of the Richwoods quadrangle, Gooding (1951, p. 42) reports a series of fractures which trend generally southwest toward Little Pilot Knob. He interprets these fractures as part of a fault zone in which downthrow occurred to the northwest.

The writer examined the southern extremity of Indian Creek in section 19, T. 38 N., R. 1 E., along the southern margin of the Richwoods quadrangle, in order to gain additional information regarding the possible extension of the Shirley Fault into this area. Within the creek bed good exposures of both Gasconade and Eminence formations were observed. As the creek was followed to the northeast, outcrops were primarily Gasconade. A series of strong northeast trending fractures were encountered which were seen in the creek bed for an interval of approximately 1,000 feet. The lithology changed rather abruptly to Eminence Formation as the east margin of the fracture zone was approached.

Based upon the above evidence the concealed fault, as shown on the geologic map (Figure 13) is extended from the Shirley Fault northward. Whether this zone actually extends into the zone of fractures described by Gooding is unknown.

This fault may have influenced the trend of joints both south and east of Little Pilot Knob. It appears to have no other important bearing upon the present study.

MAGNETIC CHARACTERISTICS OF THE AREA

The total magnetic field strength or intensity at Little Pilot Knob is about 0.569 gauss or 56,900 gammas. The inclination of the total field is $68^{o}45'$ (U. S. Coast and Geodetic Survey, 1955).

A total intensity aeromagnetic survey (U. S. Geological Survey, 1950) flown at an elevation of 1,800 feet above sea level reveals the presence of a 700 gamma anomaly at Little Pilot Knob (Figure 12). This anomaly very closely resembles the presently exposed configuration of the ridge line of Little Pilot Knob. The anomaly amounts to only 1.2 percent of the total field strength, and is a Class 3 anomaly, according to the classification presented by Jakosky (1960, p. 211). This class of anomaly is usually the result of extensive masses of volcanic or crystallir rock moderately rich in magnetite.

An average magnetic susceptibility of 5.250×10^{-3} was determined for three crushed samples of the Little Pilot Knob trachyte porphyry.[1] While substantially higher than granite susceptibilities, this figure is somewhat low when compared with susceptibilities calculated by Slichter (1929, p. 238-260). Slichter calculates an average susceptibility of 6.10×10^{-3} for trachytes and syenites. However, his calculations are based upon magnetite content as reported by chemical analysis, and are subject to interpretation.

A closed aeromagnetic total intensity anomaly of about 470 gammas is present to the east of Little Pilot Knob in the area where anomalously high Eminence-Potosi formational contacts were first reported by Dake

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[1]These determinations and subsequent ones in this study were completed through use of a susceptibility meter made available to the author by Dr. LeRoy Scharon, Department of Earth Sciences, Washington University, St. Louis, Missouri.

(1930). This anomaly is moderately broader than that existing at Little Pilot Knob, and has a magnitude of only 65 percent of the Little Pilot Knob anomaly.

A detailed vertical intensity magnetic survey was completed east of Little Pilot Knob in the area of the above described total intensity magnetic anomaly.[2] The results of this survey are shown in Figure 11. A vertical intensity anomaly of about 400 gammas is centered in the northwest quarter of section 29. This anomaly approximately corresponds with the aeromagnetic anomaly, but lies slightly farther north.

The sharpness of this anomaly suggests a near-surface origin. The magnitude of the anomaly indicates its source is likely to be an extensive mass of volcanic or crystalline rock, rather than a smaller geologic feature such as a dike or igneous pipe.

A simple but useful method for determining the depth of the buried source of a magnetic anomaly is given by Jakosky (1960, p. 213). A simplifying assumption required for the calculation is that the buried source is assumed to be a simple dipole with its lower or positive pole at infinity. A buried Precambrian hill with relatively steep flanks would approximate these conditions. With these assumptions, Jakosky's equation is as follows:

$$AB = 3/4\ d$$

where AB is the distance from the center or maximum value of the vertical

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[2]This survey was completed by use of Jalander vertical intensity flux-gate type magnetometer no. 57126, made available to the author by Mr. C. H. Arnold of Phelps Dodge Corporation. This instrument had a calibrated scale value of 9.5 gammas per scale division, and an accuracy of ± one scale division.

intensity anomaly to the point where the anomaly has one-half its maximum value, and where d equals the vertical distance from the surface to the top of the magnetic dipole.

By use of the above equation, the source of the magnetic anomaly is determined to be no deeper than 500 feet below the surface. If the steeper northern portion of the asymmetric anomaly curve is used in the calculation, the depth to the dipole may be as little as 150 feet.

An attempt is made to reproduce the magnetic anomalies in the Little Pilot Knob area by assuming a configuration of the Precambrian surface and calculating the associated magnetic field by the surface integral method. Results obtained from these calculations are presented in Chapter 10.

SUMMARY AND CONCLUSIONS

Structural, stratigraphic, and magnetic characteristics of the Little Pilot Knob area were examined in conjunction with geologic mapping of the area. Outcrops of Potosi, Eminence, and Gasconade formations were observed as near as 300 feet from the igneous knob, and as far removed as 1½ miles. Arkosic materials which might have been derived from the igneous knob were absent from the sedimentary units observed. At a single locality at the south flank of the knob, and within 300 feet of an igneous outcrop, green clay-like material, probably glauconitic clay, was observed intimately associated with dolomite of the Potosi Formation. This material may have formed as an alteration product of pre-existing feldspar or other minerals. Lithologies of units observed in outcrop appear essentially identical to those observed at other localities in the north-central Ozarks.

Dips ranging to a maximum of 15 degrees were observed adjacent to the ridge line of Little Pilot Knob. Units observed dip away from the ridge line, with strikes roughly parallel to the flanks of the ridge line. No indication of slumping was observed in any of the sedimentary units. The observed dips are much shallower than those of the underlying Pre-cambrian surface, and decrease rapidly in angle with increasing distance from the knob.

More than 150 vertical joints were mapped in the Little Pilot Knob area, primarily at two locations, and were analyzed through use of over-lapping strike diagrams. In general these joints are roughly tangential to the flanks of Little Pilot Knob. The trend of these joints may be in part influenced by the Shirley Fault.

The writer investigated unusually high Eminence-Potosi contacts in the eastern part of the Little Pilot Knob area, first reported by Dake (1930). These contacts were found to be 260 feet higher than normal for the region, and 160 feet higher than in an area immediately to the south.

The Shirley Fault was traced in order to evaluate possible relation to the present configuration of the ridge line of Little Pilot Knob. The writer concludes that this fault may influence the trend of mapped joints, but has no other significant relationship to the knob.

A detailed vertical intensity magnetic survey was completed in the eastern part of the Little Pilot Knob area where unusually high Eminence-Potosi contacts are present. A very sharp 400 gamma anomaly is present in this area. A simple depth calculation indicates the source of the anomaly to be 150 to 500 feet below the surface. A total intensity aeromagnetic anomaly of about 700 gammas is present at Little Pilot Knob. Its configuration closely resembles the exposed configuration of the knob.

In consideration of good magnetic and structural evidence, the writer concludes that a buried Precambrian hill exists 1.5 miles east of Little Pilot Knob. Its crest appears to be located near the center of the northwest quarter of section 29. It may lie as shallow as 150 feet beneath the surface.

THE CZAR KNOB AREA

INTRODUCTION

Czar Knob is the northwesternmost exposed Precambrian knob of the Central Ozarks. Its crest stands 1,000 feet above sea level. Drill hole information reveals that the knob extends upward through 1,000 feet of Cambrian sedimentary rocks. Only the uppermost portion of the knob, composed of pink granite, is exposed. Steeply dipping sedimentary rocks on the northern flank of the knob are extensively exposed by erosion.

This area was selected for detailed study for several reasons. Czar Knob is almost unique in its position at the northwestern perimeter of the Central Ozarks. The nearest similar Precambrian exposure is ten miles to the southwest. Czar Knob is well-exposed by erosion, particularly along the northern flank. Data from ten diamond drill holes provide detailed information concerning subsurface configuration of the knob, and the surrounding sedimentary rock units. Since the knob is almost entirely buried, it provides examples of geologic characteristics which may be expected where buried knobs stand very near the surface. Finally, the close control of the knob's subsurface configuration makes possible the calculation of its associated magnetic field by the surface integral method.

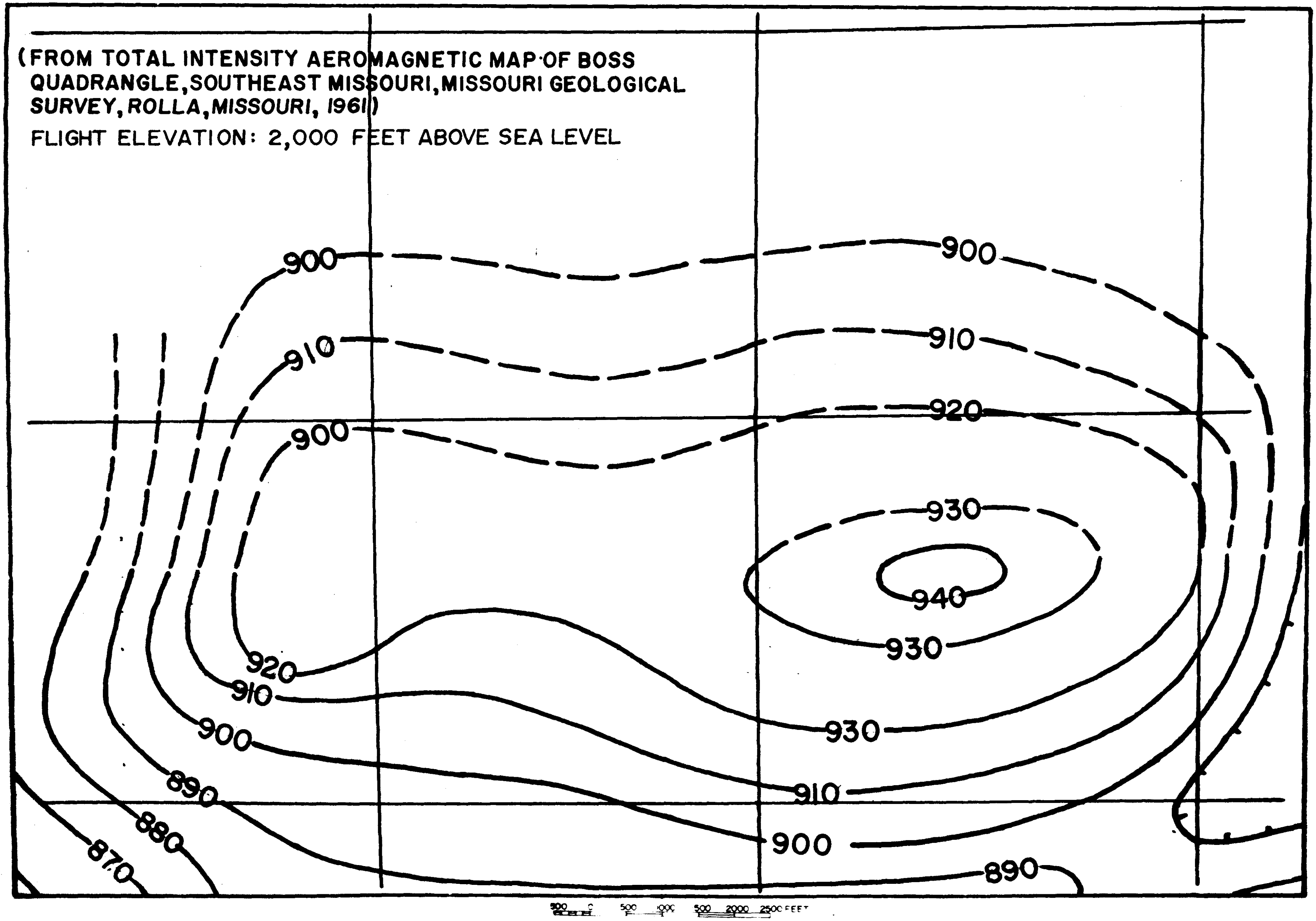
The Czar Knob area was mapped geologically at a scale of 1:6000. This map was reduced to 1:24000 scale for presentation in this report (Figure 20). All observations of dips, joints, reef structure, and breccias are plotted on the geologic map. More than 200 vertical joints were mapped in the bed of a small stream adjacent to Czar Knob. These joints are analyzed by use of overlapping strike diagrams. The magnetic susceptibility of the Czar Knob granite was determined in order to calculate the theoretical total magnetic field associated with the knob by use of the surface integral method. The results of these calculations are given in Chapter 10. Rate of decrease in dip with increasing distance from the knob was measured at two localities. The results of these measurements are shown in the form of a graph (Figure 27).

LOCATION, SIZE, AND ACCESSIBILITY OF THE AREA

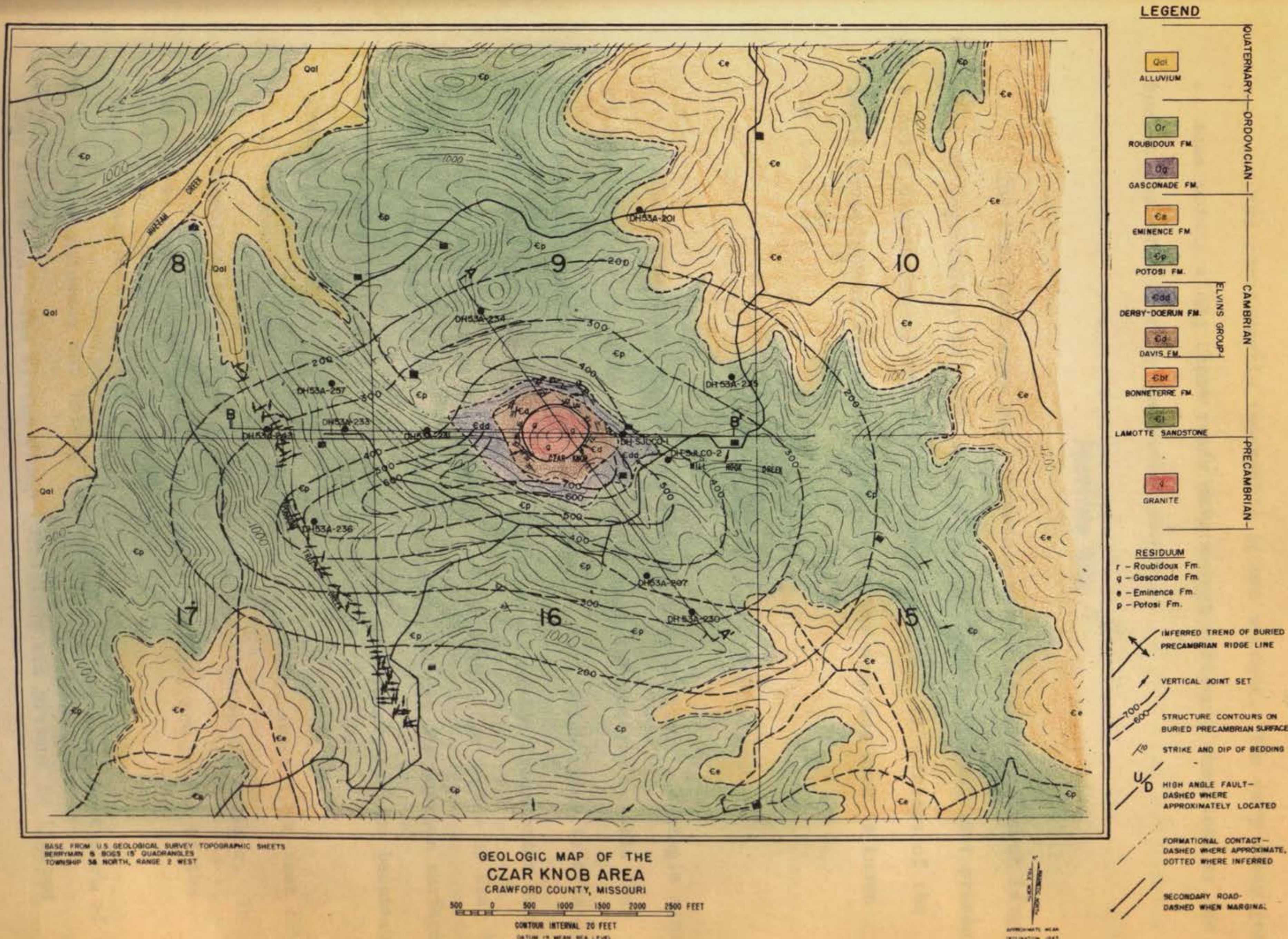
The Czar Knob area is within the southeastern portion of Crawford County, Missouri, and includes a rectangular area about two miles wide and three miles long in sections 8, 9, 10, 15, 16, 17, T. 35 N., R. 2 W. A total area of slightly less than six square miles is represented. The area is approximately three miles north of Viburnum, Missouri, in the Clark National Forest, and is immediately adjacent to the St. Joseph Lead Company Viburnum mine. The Viburnum mine shaft No. 27 is at the eastern margin of the area.

The Czar Knob area is most readily reached by turning eastward from Missouri Highway 49 onto a secondary gravel road immediately south of Dillard, Missouri. The area is two miles east of Dillard. From the north the area is reached by turning eastward on a secondary gravel road from Highway 49 two miles north of Dillard, and proceeding four miles along this road. Entrance into the area from Missouri Route Y is no longer possible due to mining and hauling activity presently underway by the St. Joseph Lead Company. Secondary roads within the area are well maintained and generally in good condition. Crossings at a number of small streams are

FIGURE 19



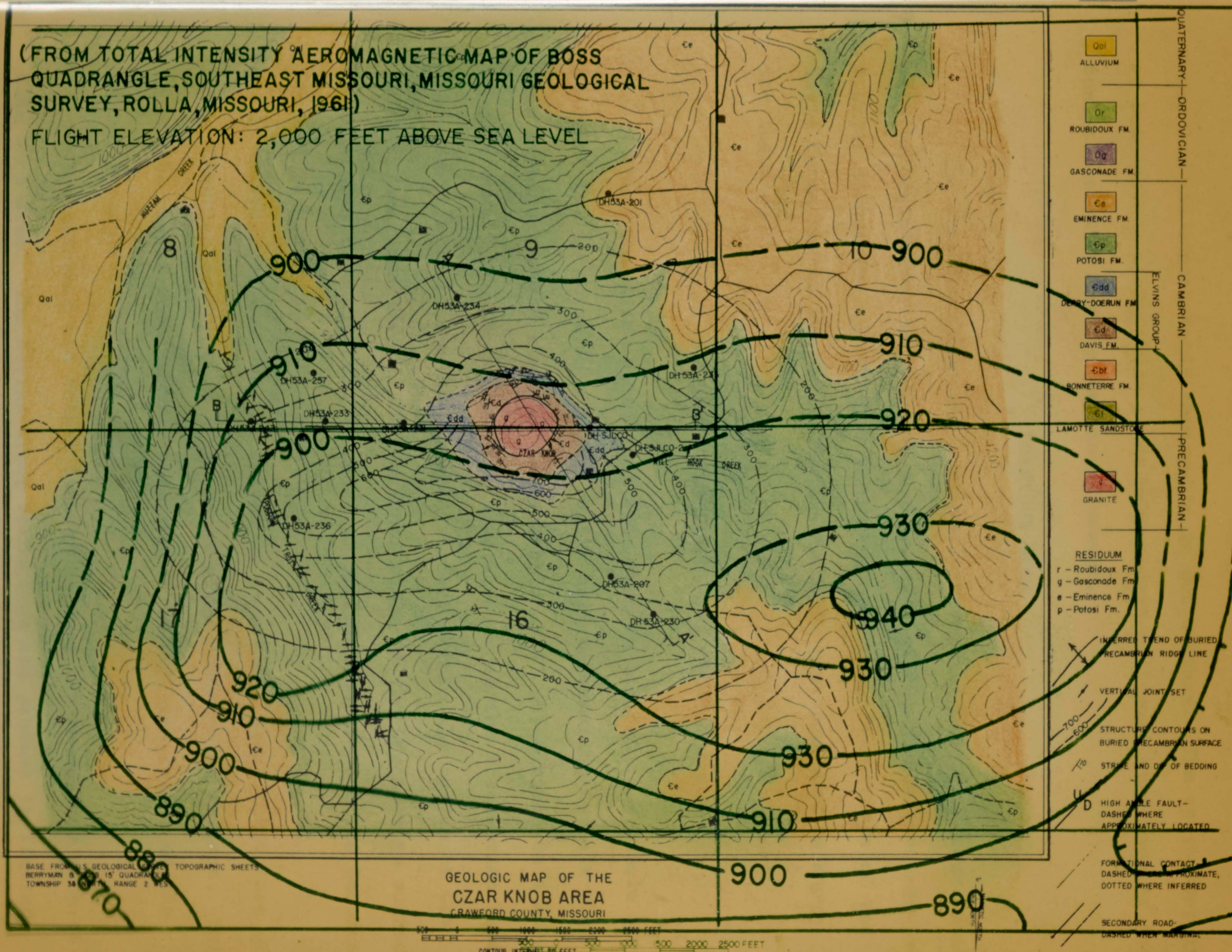
TOTAL INTENSITY AEROMAGNETIC MAP OF THE CZAR KNOB AREA



GEOLOGIC MAP OF THE
CZAR KNOB AREA
CRAWFORD COUNTY, MISSOURI

FIGURE 20

FIGURE 19



TOTAL INTENSITY AEROMAGNETIC MAP OF THE CZAR KNOB AREA

FIGURE 20

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very low and consequently impassable in wet weather. The very steep grades at some points along these roads make access difficult when snow or ice conditions exist during the winter months.

PREVIOUS WORK

The Czar Knob area was previously mapped as part of a much larger area by Degenfelder in 1950, at a scale of 1:62500. Degenfelder presents a brief discussion of the Czar Knob area, and reports outcrops of the Davis Formation on its north flank. No other previous work is known for the area.

GEOLOGIC SETTING OF THE AREA

The Precambrian granite of Czar Knob is limited to a single exposure of about thirty acres in extent. Drill hole information reveals that this exposure is the crest of a Precambrian hill which rises to a height of more than 1,000 feet above the lower levels of the Precambrian surface. The normal level of the Precambrian surface within the region of Czar Knob is at or near sea level. The regional slope of the Precambrian surface in this area is toward the northwest. The sedimentary section becomes gradually thicker in this direction.

Throughout much of the region of Czar Knob, about 1,000 feet of Upper Cambrian sedimentary rocks overlie the Precambrian surface. This thickness varies with surface topographic relief, and relief of the buried Precambrian surface.

The Eminence and Potosi formations crop out throughout much of the Czar Knob area. The Elvins Group formations are present in limited exposures adjacent to Czar Knob.

The Palmer Fault Zone bounds the northern part of the region of Czar Knob. North of the fault the Roubidoux and Gasconade formations are at the surface, with the Eminence and Potosi formations at the same level on the south block.

The stratigraphic displacement is about 400 feet in this portion of the fault zone. No other faults are known within the region of Czar Knob.

Geomorphology

The Czar Knob area is of medium relief. The greatest elevation, 1,220 feet above sea level, is at the eastern boundary of the area. The least elevation, 840 feet, is in the bed of Huzzah Creek in the northwest part of the area. The total relief is 380 feet.

The Czar Knob area is drained by several small northward and northwestward flowing creeks, which in turn drain into the much larger northward flowing Huzzah Creek. Although these streams flow directly upon bedrock throughout much of their courses, there is little evidence of structural control. Mill Rock Creek, in its curving course around the north flank of Czar Knob, provides the single exception.

The area is characterized by high, relatively flat-topped ridges and deep stream valleys paralleled by steep bluffs and slopes. Except for the area immediately adjacent to Czar Knob, only Eminence and Potosi formations crop out. These formations respond very similarly to erosion. In general, as within the Little Pilot Knob area, the Eminence Formation forms the steeper slopes and bluffs. However, the difference is not as readily apparent here.

Czar Knob forms a very marked prominence adjacent to the channel of Mill Rock Creek. The stream flows in a broad arch around the north flank of the knob, and crosses the steeply dipping beds to the east and west of Czar Knob. It appears to show no deference to structure other than that of the granite knob itself. The topographic expression of Czar Knob is an outstanding example of differential erosion. As Mill Rock Creek progressively deepened its channel, the Czar Knob granite was encountered, the stream direction controlled, and this ancient hill resurrected.

Immediately north of Czar Knob, massive and somewhat irregular reef structure in the upper units of the Derby-Doerun Formation is weathered in strong relief in contrast to the normal thin-bedded units of the formation.

STRATIGRAPHY OF EXPOSED FORMATIONS

Five mappable rock units, including the Czar Knob granite, are identified in the Czar Knob area. The sedimentary rocks consist almost entirely of dolomite with associated chert and quartz druse. Flat pebble conglomerates, reef structure, and sedimentary breccias were observed in sedimentary units of the area.

Czar Knob granite

The Czar Knob granite crops out at the surface in the form of a low rounded hill, immediately south of Mill Rock Creek. The total outcrop area of the granite is approximately thirty acres. Widely spaced vertical joints, ranging from three to ten feet apart, occur within the granite.

These joints trend N. 30° W., North, and N. 70° E. Blocks separated by joints have weathered through exfoliation into large oval and elliptical boulders as much as five feet in diameter. Surfaces are highly weathered and are easily granulated. Feldspars are extensively altered to kaolinite.

The granite is medium to coarse-grained; the gross color is medium pink; it has subhedral to euhedral flesh pink feldspar 80 percent anhedral quartz 15-20 percent, and accessory dark minerals include biotite, pyrite, chlorite, and magnetite, 0-5 percent. For a detailed microscopic description and chemical analysis of the Czar Knob granite, the reader is referred to a study by French (1956, pp. 25-27).

Elvins Group: Davis Formation

The Davis Formation crops out in a very limited area immediately adjacent to Czar Knob. A description of an outcrop on the northeast flank is as follows:

Top of Outcrop

Limestone, light gray, medium crystalline, with thin elongate lenses of limestone (flat pebble conglomerate) medium brown, finely crystalline; elongation of lenses parallel bedding, lenses weather in relief, individual beds about one foot thick, dip 30 degrees N. 55° E., unit may have undergone slumping........................2' 0"

Dolomite, dark, bluish gray, medium brown on weathered surface, medium to finely crystalline, with spherical grains of glauconite 0.5mm, thin flaggy beds, moderately fractured with fractures trending S. 10° W., bedding dips 31 degrees northeast, strike N. 35° W., granite float abundant..5' 0"

Base of outcrop in bed of Mill Rock Creek

Another small outcrop of the Davis Formation is at the northwest margin of Czar Knob. Its description follows:

Top of outcrop

Shale, medium blue-gray, dolomitic, interbedded with dolomite, dark, bluish gray with thin and flaggy beds; shale beds vary in thickness from 1" to 4", dolomite displays blocky fractures and is somewhat shaly; shale weathers buff, light blue, and gray................3' 0"

Bottom of outcrop in bed of Mill Rock Creek

The flat-pebble conglomerate, glauconite, and shale beds are characteristics of part of the Davis Formation. The total thickness of the Davis Formation is impossible to determine accurately, because a major portion of the formation lies within the stream bed of Mill Rock Creek and under its associated alluvial material. By measuring from the base of the Potosi Formation at the top of the bluff north of Czar Knob, and allowing for known dips of the units involved, the writer estimates that no more than 150 feet of Elvins Group sediments are present in this interval. About half this interval, or seventy five feet, is believed to be occupied by units of the Davis Formation.

Elvins Group: Derby-Doerun Formation

Excellent exposures of the Derby-Doerun Formation occur immediately north of Czar Knob. A sixty foot stratigraphic interval of this formation is exposed in a bluff overlooking Mill Rock Creek. Depending upon location in relation to Czar Knob, the beds dip to the northeast, north, and northwest. The greatest observed dip at this location was 14 degrees, although dips of 30 degrees exist only 100 feet to the south. A description of this interval follows;

Top of bluff

Dolomite, light gray to buff, massive, finely crystalline, no bedding planes visible, weathers in strong relief, grades laterally and vertically into thin to medium-bedded dolomite. (Algal Reef Structure)..15' 0"

Dolomite, medium gray, finely crystalline, silty, thin flaggy, irregular beds, weathered surface medium to dark gray, dip 14 degrees northeast, strike N. 36° W..............28' 0"

Covered interval, thin-bedded dolomite float.................17' 0"

Base of outcrop, alluvium of Mill Rock Creek

An outcrop at the western margin of Czar Knob assigned to the lower portion of the Derby-Doerun Formation is as follows:

Dolomite, medium gray, finely crystalline, angular fracture, dense, massively-bedded, individual beds average three feet in thickness, dark brown to black on weathered surface, weathers in smooth surfaces, dip 10 degrees northwest, strike N. 14° E...6' 0"

The thin-bedded and silty character, and general absence of chert suggest these beds are units of the Derby-Doerun Formation.

A striking feature of the upper portion of the Derby-Doerun Formation north of Czar Knob is a zone of massive and irregular algal reef structure. This material is distinctive in its complete lack of bedding and strong resistance to weathering. No macroscopic internal structure is discernable for comparison with the well-known *Cryptozoon* reefs of the Gasconade Formation. The Derby-Doerun reefs exhibit a definite curvature about the northern margin of Czar Knob. Whether the reef extends completely around Czar Knob is not known, as outcrops of this stratigraphic interval do not occur south of the knob. Figures 22, 23, and 24 are photographs of the reef structure.

Potosi Formation

The Potosi Formation is at the surface throughout a large portion of the Czar Knob area. Its chief distinguishing characteristics here, as elsewhere in the region, are its light brown color, medium to fine crystallinity, and an abundance of drusy quartz. The almost complete lack of bedding planes makes dip determination difficult to impossible from the outcrop. Numerous vertical joints are recognized in the Potosi Formation along Possum Trot Creek.

Eminence Formation

The Eminence Formation occurs only at higher elevations within the Czar Knob area and more particularly within the northeastern portion. The general lithology of the formation is similar to that observed for the Little Pilot Knob area.

A strongly brecciated zone within the Eminence Formation in the northern part of the Czar Knob area in the NW¼, NW¼, section 9 has the following characteristics:

Top of outcrop (side of hill)

Dolomite, medium to coarsely crystalline, light gray and light brown, intensely brecciated; fragments range from cobble to sand size, angular to subrounded; matrix light brown, fragments light gray, outcrop weathered very light gray to white.. 15' 0"

Base of outcrop in stream gulley.

This breccia is not attributed to faulting, as fault evidence is lacking at this outcrop, and in the entire Czar Knob area.

Snyder and Odell (1958, pp. 899-926) identify and describe the origin of a large number of sedimentary breccias within the Bonneterre Formation of the Central Ozarks. As Snyder and Odell demonstrate, the sedimentary breccia develops as the dip of the sediments increases due to differential compaction between lime sands (calcarenites) and lime muds (calcilutites) of basinal areas. However, nothing has been published concerning breccia zones within formations younger than the Bonneterre within the Central Ozarks.

Snyder and Odell (1958, p. 906-908) describe one type of sedimentary breccia as follows:

> Corners and edges of fragments are angular; the blocks have undergone little abrasion. The matrix of the dolomite breccia consists of fine to medium-grained crystalline brown dolomite with varying proportions of black shale.

In comparing the Czar Knob breccia with those described by Snyder and Odell, the writer notes some similarities. Snyder and Odell report deformed but traceable bedding in sedimentary breccias of the Bonneterre. What seems to be badly deformed but partly traceable bedding is recognized within the Czar Knob breccia. Snyder and Odell report the breccias are composed of essentially angular fragments which have undergone little abrasion. The Czar Knob breccia is composed of predominantly angular fragments.

In view of the above considerations, it is possible that the Czar Knob breccia had an origin similar to those described by Snyder and Odell. The breccia may have developed with submarine sliding within the Eminence Formation at the north flank of Czar Knob. A more clastic calcarenite facies may have existed adjacent to the knob, which graded into a calcilutite facies with increasing distance from the knob.

<u>Quaternary Surficial Deposits</u>

Except within the vicinity of Huzzah Creek, streams of the Czar

Knob area flow directly upon bedrock throughout much of their courses. Moderately extensive deposits of Recent alluvial material floor the valley of Huzzah Creek. No other Quaternary deposits are recognized within the Czar Knob area.

DEPOSITIONAL ENVIRONMENT OF THE CZAR KNOB AREA

Sedimentary phenomena which offer evidence of depositional environments within the Czar Knob area include flat-pebble conglomerates and blue-gray shale of the Davis Formation, arkosic material and reef structure of the Derby-Doerun Formation, and possible sedimentary breccia within the Eminence Formation. No fossils were observed in rocks of the Czar Knob area.

A flat pebble conglomerate (figure 21) crops out next to the granite at the north flank of the knob. The conglomerate dips at an angle of 30 degrees. Long axis of the included pebbles parallel the dip of the enclosing sediments. Blue-gray dolomitic shale is exposed at the northwestern and northeastern flanks of the knob, again within a few feet of granite.

A few angular feldspar fragments, up to 3mm in diameter and almost completely altered to kaolinite, are identified within units of the Derby-Doerun Formation at the southeastern flank of the knob, about 150 feet from exposed granite.

The algal reef structures are in the upper portion of the Derby-Doerun Formation. The structures are within 300 feet of exposed granite, and extend in an arc around the north flank of the knob. No fore-reef or back reef facies were observed. The reef structures exist as anomalous bodies within otherwise typical Derby-Doerun sedimentary units. They are similar to one illustrated by Moore (1949, p. 106) and described as a large calcareous algal mass in Upper Cambrian marine deposits of Central Texas. The reef zone appears to be no more than twenty five feet in width. Within this zone, structures are irregular and discontinuous both vertically and horizontally. At one locality bedding planes bend upward and downward around the reef structure (Figure 23).

The presence of massive reef structure to the north of the knob, and the flat-pebble conglomerate, probably formed through burial of sun-cracked surfaces, are suggestions of shallow water conditions near the knob. The arkosic material of the Derby-Doerun Formation indicates that sufficient current existed to carry some relatively large fragments more than 150 feet from the knob. This material indicates the crest of Czar Knob was exposed at time of deposition of these sedimentary units.

Czar Knob evidently existed as a high in Late Cambrian seas. Its crest appears to have remained exposed until Late Derby-Doerun time. Water depths adjacent to the knob seem to have varied somewhat, but must have been generally shallow.

STRUCTURE OF THE AREA

The Czar Knob area is characterized by nearly flat-lying sedimentary rocks. In the immediate area of the knob, steeply inclined beds crop out. No faults are known in the area. Subsurface structure contours of Czar Knob, as shown on the geologic map of the area (Figure 20), indicate the buried hill is roughly oval in outline, with relatively steep flanks. Sedimentary units adjacent to the knob dip parallel to its

Figure 21. Flat-pebble conglomerate of the Davis Formation. Northeast margin of Czar Knob. See description above. (SW¼, SE¼, section 9, T. 35 N., R. 2 W.)

Figure 22. Massive algal reef structure weathered in relief adjacent to irregularly bedded units of the Derby-Doerun Formation (northwestern margin of Czar Knob).

Figure 23. More detailed view of reef structure shown above. Note bedding planes bending around reef, others grading laterally into the structure.

Figure 24. Massive algal reef structure weathered in relief adjacent to irregularly bedded units of the Derby-Doerun Formation (northwestern margin of Czar Knob).

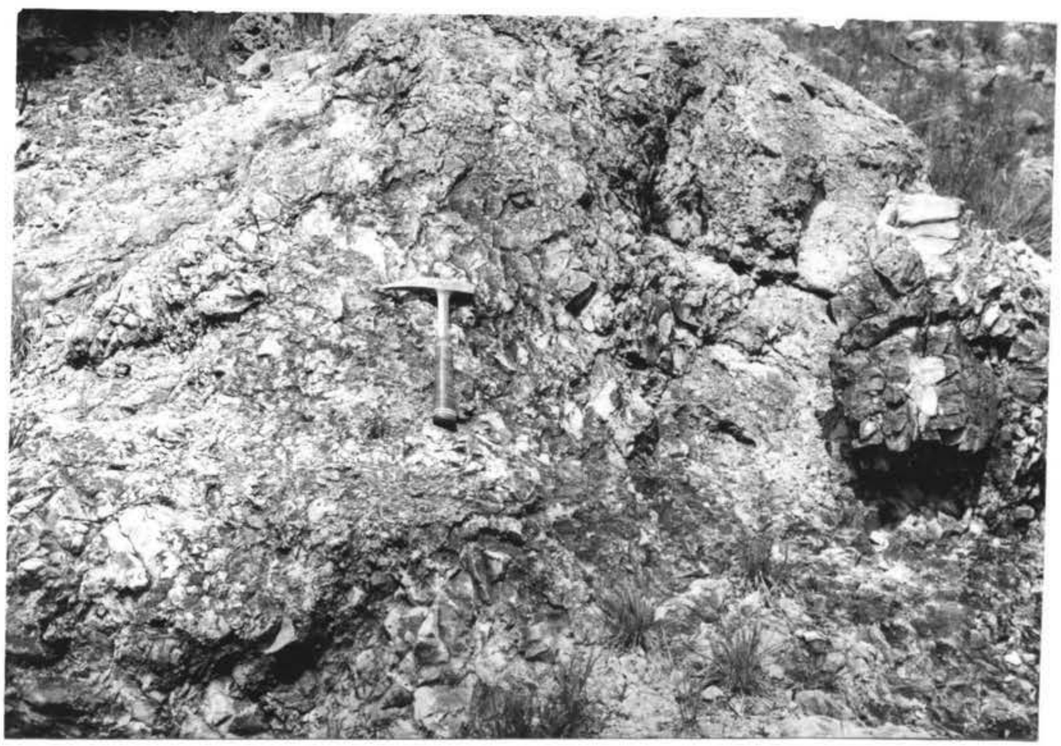

Figure 25. Strongly brecciated zone within the Eminence Formation 4,500 feet northeast of Czar Knob. Note suggestion of traceable bedding above and adjacent to geologic hammer.

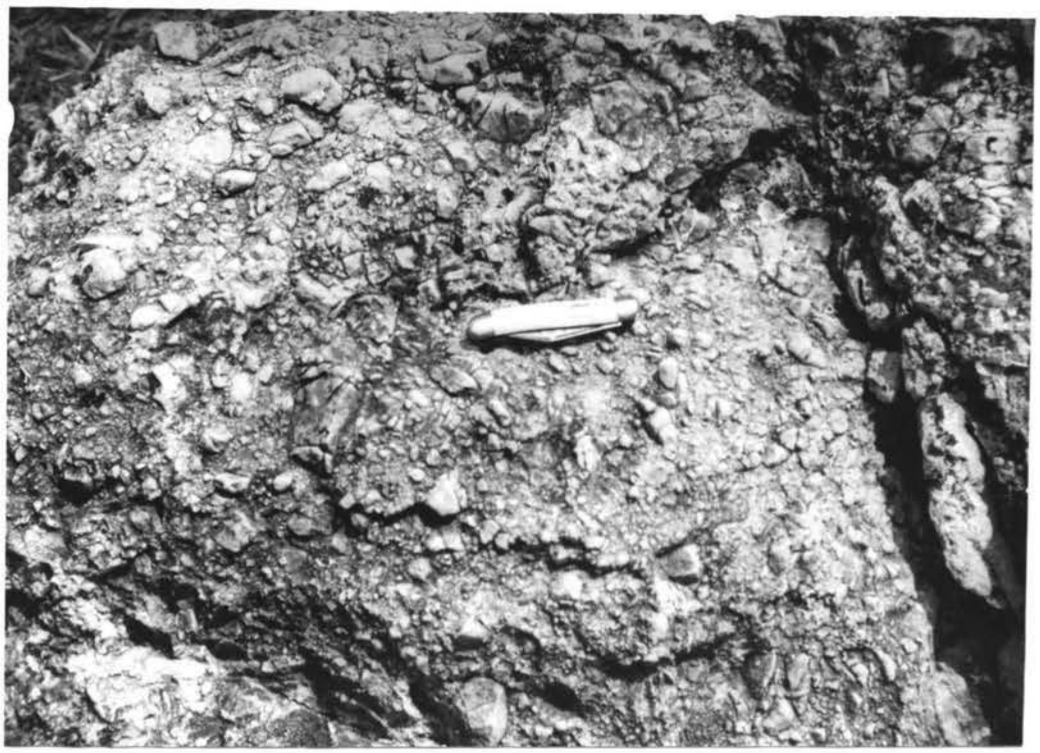

Figure 26. Detailed view of a portion of breccia zone shown in Figure 25. Rounding of fragments is due primarily to surface weathering. Most fragments seen in fresh fracture are angular. (NE¼, NE¼, section 9)

flanks, but at a much lower angle. Joints are not abundant in the area, except in the stream bed of Possum Trot Creek, where there are more than 200 vertical joints within a one mile interval of the creek.

Peripheral Dips Adjacent to Czar Knob

The exposed uppermost flanks of Czar Knob slope at angles ranging from 5 degrees at the western flank to about 30 degrees at the northeastern flank. Where these flank beds pass beneath the surface, the slope is much steeper. On the northeastern flank the subsurface slope reaches a maximum value for the knob of 54 degrees. On the western flank of the knob, where the subsurface slope is about 20 degrees, overlying units of the Derby-Doerun Formation dip at angles ranging from 10 degrees to 13 degrees. On the northeastern flank where there is a 54 degree slope of the Precambrian surface, overlying sedimentary units dip at only 31 degrees.

Dips were measured along profiles taken at right angles to Czar Knob, and plotted on graph paper opposite distance in order to demonstrate rate of decrease in dip with increasing distance from the knob. Figure 27 shows the results of these measurements..

The decrease in dip along the two profiles of measurement is rapid and essentially linear for a distance of about fifty feet from the knob. Within this fifty foot interval the dips decrease to less than half their maximum values. Beyond fifty feet from the knob, dips continue to decrease, but at a slower rate. On the north flank, in the interval from fifty to 300 feet from the knob, rock units show a decrease in dip of only 7 degrees, compared with 19 degrees for the fifty foot interval adjacent to Czar Knob.

On the northeast flank, in the interval from fifty feet to 200 feet,

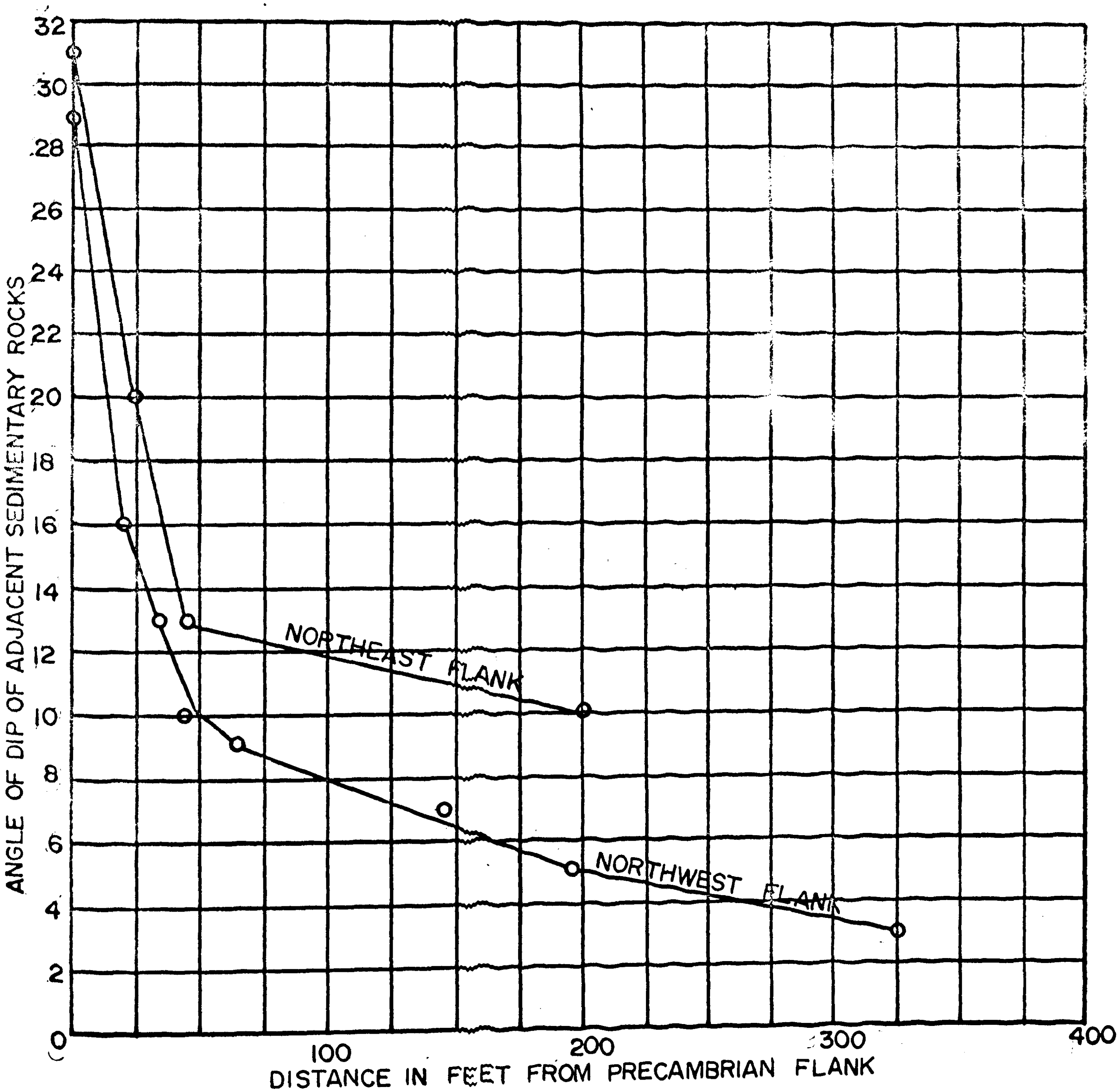

FIGURE 27. DECREASE IN ANGLE OF DIP WITH INCREASING DISTANCE FROM EXPOSED PRECAMBRIAN FLANK — NORTH FLANK OF CZAR KNOB

the dip decreases only 3 degrees, compared with a decrease of 18 degrees for the fifty foot interval adjacent to the knob. This general relationship probably holds for other flanks of the knob, although insufficient data are available for detailed profiles.

As shown by the figures in parentheses in Figure 27, rapid decreases in dip take place above portions of the buried Precambrian flanks where the slope is relatively uniform and much steeper. At distances greater than 1,500 feet from the exposed flanks of Czar Knob, outcropping sedimentary units are essentially flat-lying.

Joint Patterns Within the Area

A few vertical joints were observed in sedimentary rocks immediately adjacent to Czar Knob. These were either radial or tangential in respect to the knob. Only one general locality within the Czar Knob area contains a significant number of exposed joints.

There are more than 200 vertical joints in the bed of Possum Trot Creek within a distance of less than one mile. In spite of moderately good outcrops in other streams of the area, very few joints were noted elsewhere.

A Brunton compass and pace survey was completed along Possum Trot Creek at a scale of one inch equals fifty feet. The traverse commenced at the stream crossing in the SW¼ of section 16, T. 35 N., R. 2 W., and closed on a fence along the north line of section 17, T. 35 N., R. 2 W. The results of this survey are plotted in Figure 28. Location of the traverse, position of the observed joints, and contours on the buried Precambrian surface are shown for comparative purposes. Strike diagrams are plotted along the left margin of the figure with 50 percent overlap. Each diagram shows the strike of joints in the creek bed immediately opposite its location.

Beginning with the uppermost three strike diagrams, it can be seen that the dominant strike of joints within this interval of Possum Trot Creek is N. 60°-80°E. A smaller number of joints strike north and about S. 60°E. The buried northwest flank of Czar Knob strikes about N. 60°-80°E. in this area.

Dominant strikes as shown by the three central strike diagrams are east, N. 70°-90°E., S. 70°-90°E., and N. 10°-20°E. Joints in this interval of Possum Trot Creek are directly opposite the buried nose of an elongate ridge extending southwestward from the exposed portion of Czar Knob.

The lowest three strike diagrams indicate dominant strikes of East, N. 80°E., S. 80°E., and N. 10°-20°E. The south flank of Czar Knob extends almost due east along this interval of Possum Trot Creek.

The south flank of the buried hill trends generally eastward, and a significant portion of the joints in this area show an easterly trend parallel to the east-trending flank. The buried northwestern flank extends generally northeastward. In the area of the northwestern flank, a large number of joints have a northeasterly trend roughly parallel to the buried flank. Opposite the elongate crestal ridge of the buried Czar Knob, joints lose their dominant northward and eastward trends, and spread around the nose of the knob in a more general fashion.

GEOLOGIC CROSS-SECTIONS OF CZAR KNOB

Two geologic cross-sections of Czar Knob are presented in Figure 29.

The locations of these sections are shown in Figure 20, the geologic map of the Czar Knob area. The cross-sections are drawn at a scale of 1 inch equals 500 feet, and have no vertical exaggeration. Formational contacts and dips of exposed sedimentary formations are shown as observed and mapped in the field. Subsurface information was obtained from drill holes shown on the cross-sections.

These cross-sections show graphically the Lamotte Formation and Bonneterre Formation truncation or pinch-out adjacent to Czar Knob. The Davis Formation thins to about half its maximum thickness. The formation may have pinched out adjacent to the now eroded upper flanks of Czar Knob. The Derby-Doerun Formation shows only limited thinning, and appears to have extended entirely across the knob before being removed by erosion.

A partial discordance in dip of the sedimentary units in relation to the underlying Precambrian surface is seen at the flanks of the knob and along the north and south slopes. In general the cross-sections show the flanks of the knob to be sloping at angles substantially greater than the dips of the overlying sedimentary rocks.

MAGNETIC CHARACTERISTICS OF THE AREA

Total magnetic field strength at Czar Knob is about 56,500 gammas, or 0.565 gauss. Inclination of the total field is about 68°15' (U. S. Coast and Geodetic Survey, 1955).

An average magnetic susceptibility of 1.147×10^{-3} c.g.s. units was determined for an unweathered sample of the Czar Knob granite.[3]

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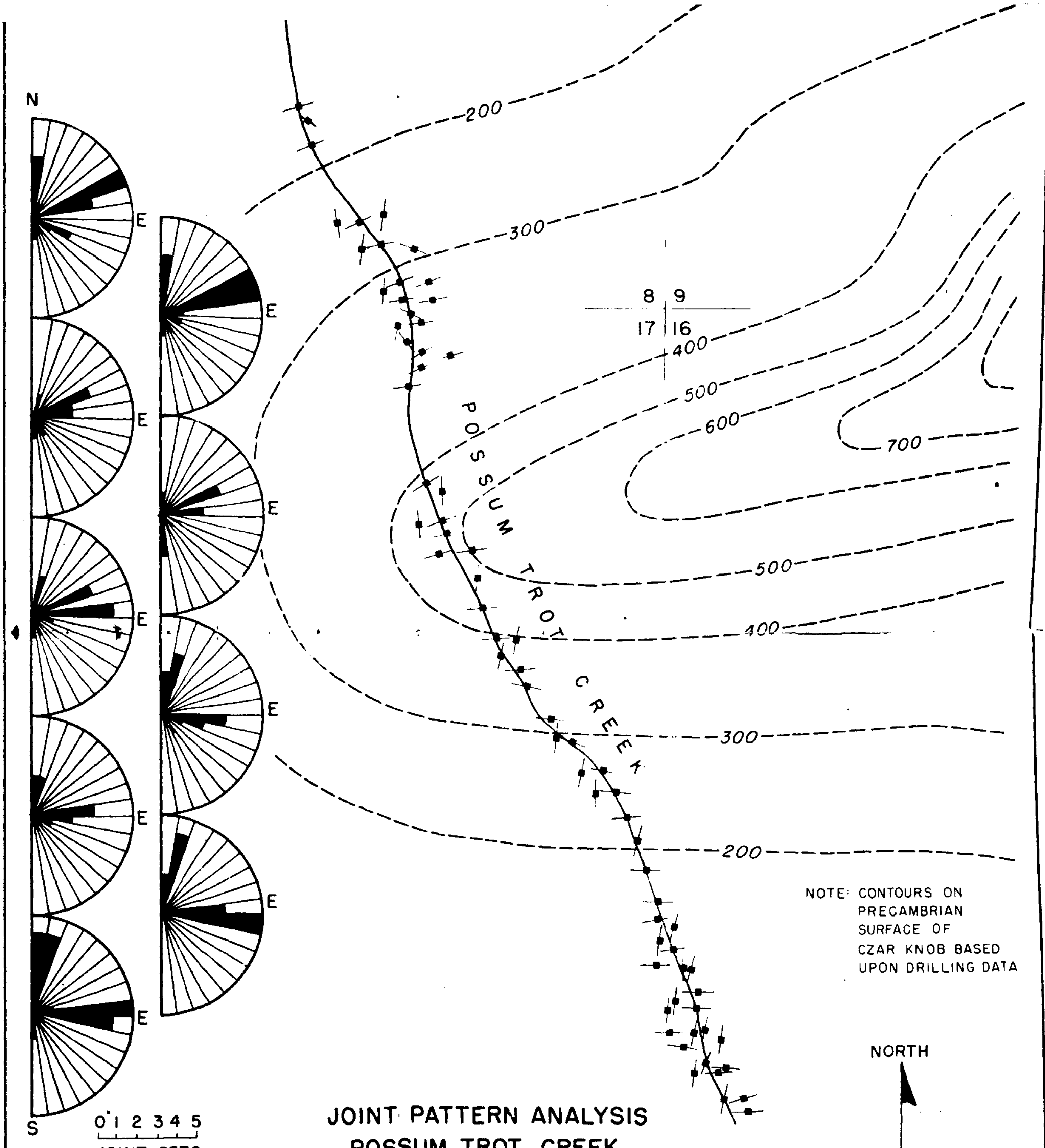
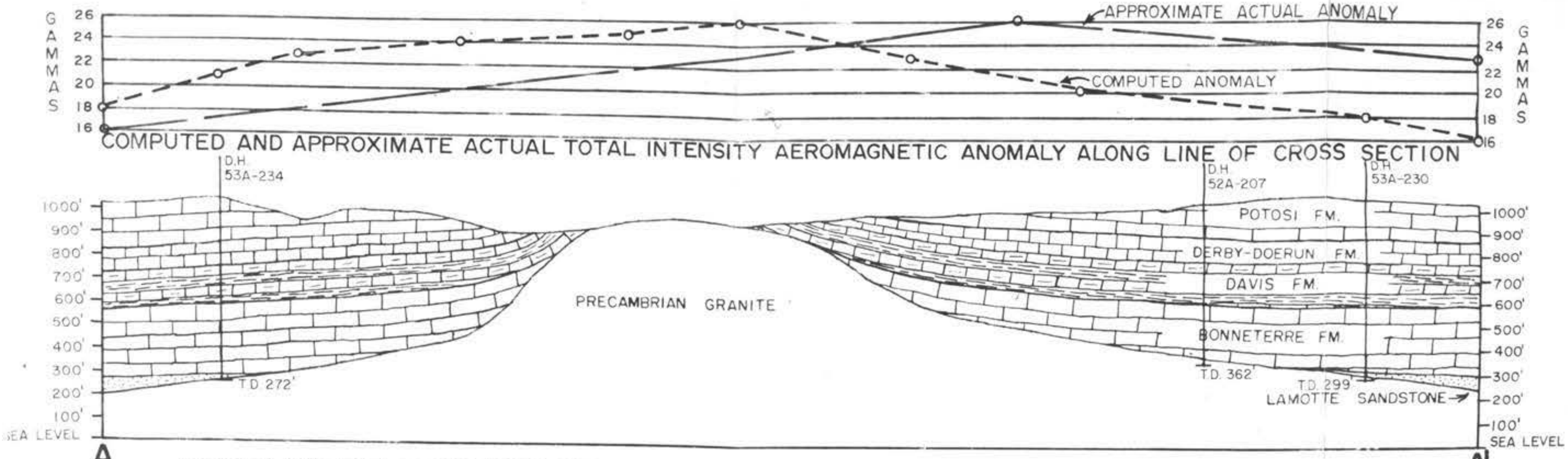
[3]This sample was supplied to the writer by Dr. William C. Hayes, State Geologist, Missouri Geological Survey, Rolla, Missouri.



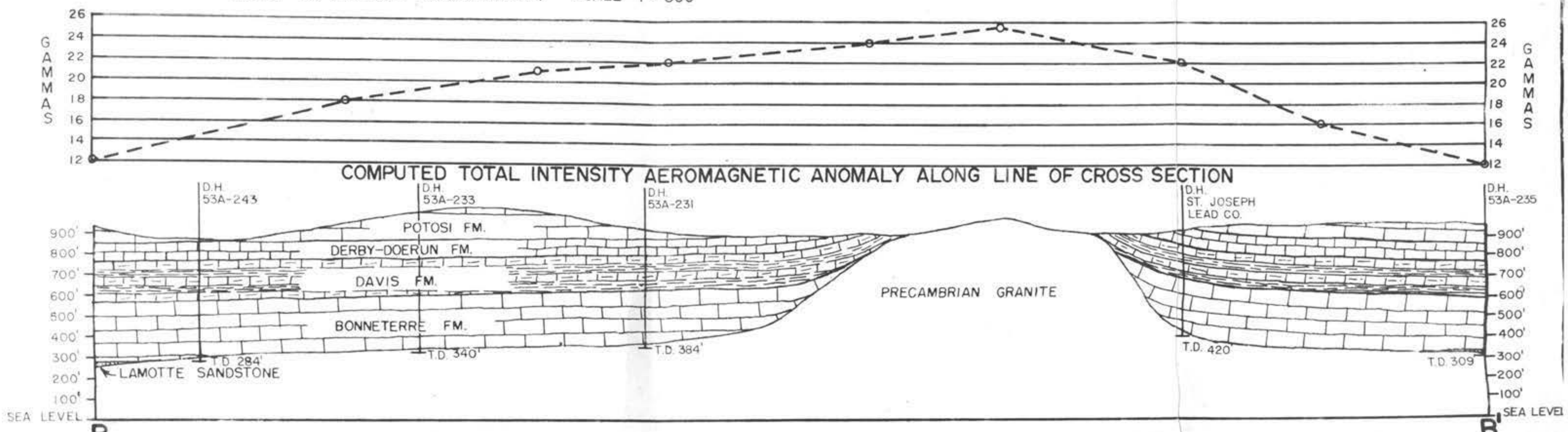
JOINT PATTERN ANALYSIS
POSSUM TROT CREEK
CZAR KNOB AREA
SCALE 1" = 500'
SURFACE ELEVATION APPROXIMATELY
900 FEET ABOVE SEA LEVEL

FIGURE 28



NORTHWEST **NORTHWEST-SOUTHEAST GEOLOGIC CROSS SECTION, CZAR KNOB** SOUTHEAST

NOTE: GEOLOGIC CROSS SECTIONS BASED UPON SURFACE OUTCROP DATA AND A PRECAMBRIAN SURFACE CONTOUR MAP COMPILED FROM DIAMOND DRILL HOLE INFORMATION. SURFACE TOPOGRAPHY FROM U.S.G.S. TOPOGRAPHIC MAPS. NO VERTICAL EXAGGERATION. SCALE: 1" = 500'



WEST **EAST-WEST GEOLOGIC CROSS SECTION, CZAR KNOB** EAST

FIGURE 29

This figure is very low when compared with most igneous rock susceptibilities. However, granites, and particularly those that are very low in ferro-magnesian minerals characteristicly have low susceptibilities. In the case of the Czar Knob granite, a low susceptibility is suggested by its predominant quartz and feldspar content.

Since the Czar Knob area lies at the boundary of the Berryman and Boss quadrangles, it is partly covered by two aeromagnetic surveys. The southern one-third of the area is covered by an aeromagnetic map of the Boss quadrangle (Missouri Geological Survey, 1961), flown at an elevation of 2,000 feet above sea level, and contoured with a 10 gamma contour interval. The northern two-thirds is covered by an aeromagnetic survey of the Berryman quadrangle (U. S. Geological Survey, 1951), flown at an elevation of 1,800 feet above sea level, and contoured with a 50 gamma contour interval.

Because of different contour intervals and slightly different flight elevations, the two surveys are not well-matched. The two maps reveal the presence of a closed total intensity anomaly of about 40 gammas in proximity to Czar Knob (Figure 19). The anomaly very roughly corresponds to the gross outline of Czar Knob, but is much broader. The magnitude of the anomaly is much lower than one earlier described in the Little Pilot Knob area.

In consideration of the size and pronounced relief of Czar Knob, the associated magnetic response might seem unreasonably low. It is relatively inconspicuous among several larger closed magnetic anomalies in both the nearby Berryman and Boss quadrangles. However, the primary factor in determining the magnitude of a magnetic anomaly is the magnetic susceptibility of the anomalous rock material. In the case of the Czar Knob granite the low susceptibility is reflected by a low aeromagnetic anomaly.

SUMMARY AND CONCLUSIONS

Czar Knob is an isolated exposure of granite in an area of nearly flat-lying sedimentary rocks of Late Cambrian age. Drill-hole data indicate this granite exposure is the crest of a Precambrian hill that extends upward through nearly 1,000 feet of sedimentary rocks. This granite exposure has weathered in relief, causing Mill Creek to follow a circular course around the knob's north flank.

Evidences of depositional environment in the Czar Knob area include flat-pebble conglomerate and blue-gray shale of the Davis Formation, arkosic material and reef structure of the Derby-Doerun Formation, and possible sedimentary breccia within the Eminence Formation. The arkosic material, reef structure, and breccia suggest the crest of Czar Knob existed as a high in Late Cambrian seas. Its crest probably was completely buried by sediments in Late Derby-Doerun time. Water depths were generally shallow adjacent to the knob.

Sedimentary rocks adjacent to Czar Knob dip away from the flanks of the knob and strike parallel to the outline of the knob. These dips are as great as 31 degrees at the north flank of the knob. The underlying Precambrian surface slopes at angles as great as 54 degrees. Sedimentary rocks above the Precambrian surface consistently dip at lower angles than does the underlying Precambrian surface.

A large number of vertical joints are present in Possum Trot Creek, about one-half mile west of the crest of Czar Knob. The strikes of these joints were analyzed by use of overlapping strike diagrams. Most joints show strikes either parallel or perpendicular to the buried flanks of Czar Knob.

Aeromagnetic maps of the Czar Knob area show a closed anomaly with a magnitude of about 30 gammas at its crest. This anomaly is low in magnitude, but appears to accurately reflect the low magnetic susceptibility of the Czar Knob granite.

THE TAUM SAUK AREA

INTRODUCTION

The Taum Sauk area[4] lies within the St. Francois Mountains in a region of broad rhyolite porphyry ridges that commonly attain heights of more than 1,600 feet above sea level. Taum Sauk Mountain, a rhyolite porphyry ridge 1,772 feet above sea level and the highest point in the State of Missouri, is about two and one-half miles east of the Taum Sauk area. In this area sedimentary rocks, of Late Cambrian and Early Ordovician age, are at lower elevations, usually in narrow valleys between high Precambrian ridges.

The Taum Sauk area was selected for detailed study because of its geographic location within the Central Ozarks, and because of a unique exposure of Late Cambrian sedimentary rocks adjacent to a high Precambrian ridge. This excellent exposure resulted when the Union Electric Company, St. Louis, Missouri, excavated a tail race and tunnel in connection with its now completed hydroelectric project in the area. The section exposed within the tail race affords an opportunity to study in detail the relation of sedimentary rocks to the buried, but now extensively resurrected Precambrian topography.

The Taum Sauk area was mapped geologically at a scale of 1:6000. The map was reduced to a 1:24000 scale for presentation in this report (Figure 31). Nearly 100 vertical joints in the area are shown on the

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[4]The name Taum Sauk is derived from the Union Electric Company Taum Sauk project, located in the area. The Taum Sauk Cut is located at the western margin of Proffit Mountain.

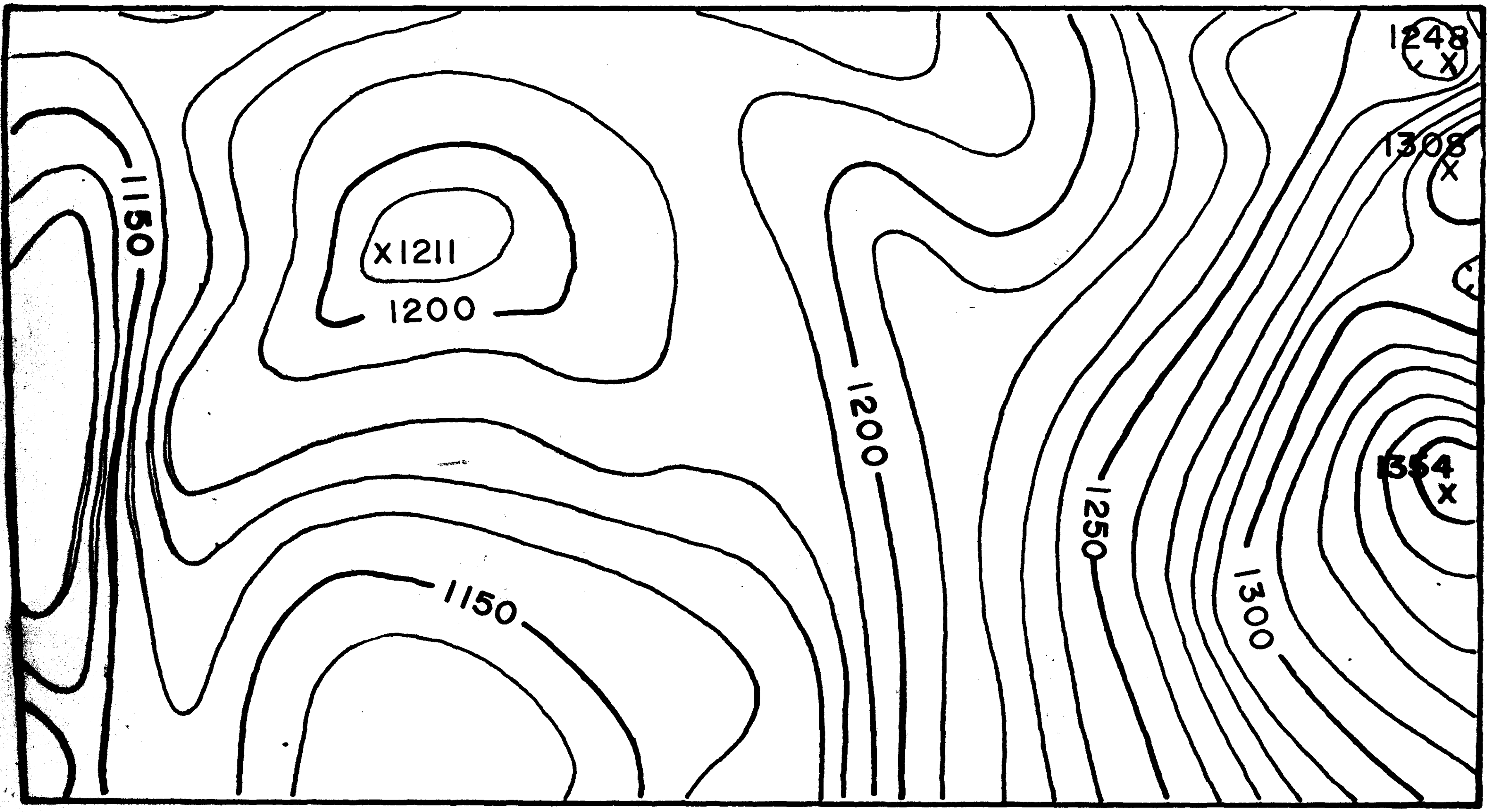
geologic map. Strikes and dips of sedimentary rocks, where measurable, are also indicated. A previously unmapped but exposed Precambrian knob, located during this study, is also shown. The Taum Sauk tail race cut was studied in detail and descriptions of rock units within the cut are presented. Twelve oriented thin sections were prepared from representative rock samples, and photomicrographs of five of the thin sections are included in this study. Certain evidences of sedimentary environments noted during the geologic mapping are discussed. The rate of decrease in dip with increasing distance from the Precambrian ridge was measured in the Taum Sauk tail race. The results of these measurements are shown in the form of a graph (Figure 49). Finally, an aeromagnetic map of the Taum Sauk area at the same scale as the geologic map is included. The relationship between geology of the area and the area's magnetic response is discussed.

LOCATION, SIZE, AND ACCESSIBILITY OF THE AREA

The Taum Sauk area is in the northeastern part of Reynolds County, Missouri, in all or parts of sections 16, 17, 18, 19, 20, 21, 28, 29, and 30. Slightly more than four square miles is represented in the mapped portion.

The area is five miles north of Lesterville, Missouri, and about twenty miles west of Ironton, Missouri. Johnson Shut-ins State Park is immediately north of the area.

The eastern part of the area can be reached by turning northward on a secondary road from Missouri Highway 21 about one mile east of Lesterville, Missouri. The central and western part of the area is



TOTAL INTENSITY AEROMAGNETIC MAP OF THE TAUM SAUK AREA

500 0 500 1000 1500 2000 2500 FEET

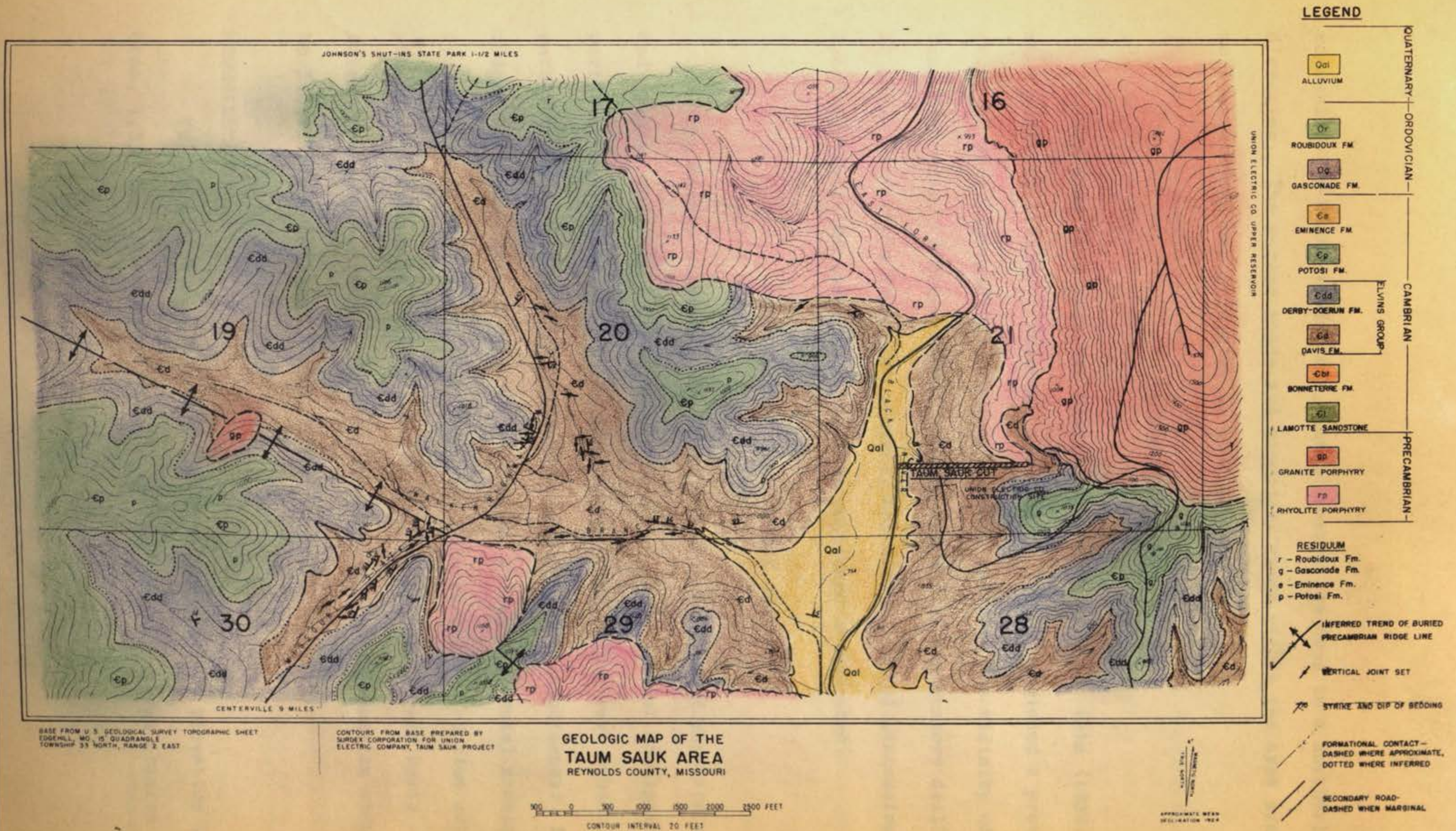
CONTOUR INTERVAL 10 GAMMAS

FROM TOTAL INTENSITY AEROMAGNETIC MAP OF EDGEHILL QUADRANGLE, MISSOURI

(MISSOURI GEOLOGICAL SURVEY, ROLLA, MISSOURI, 1961)

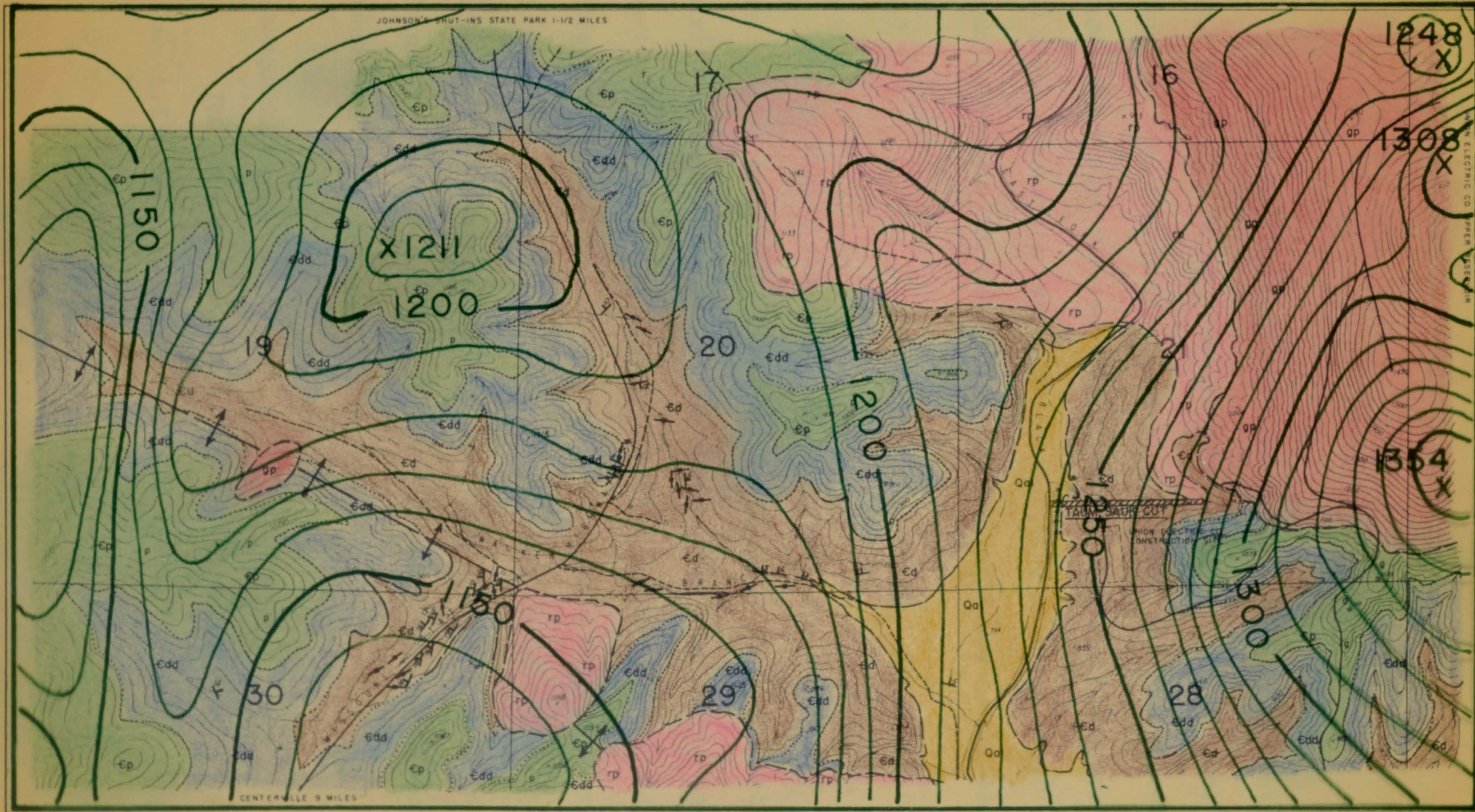
FLIGHT ELEVATION: 2,000 FEET ABOVE SEA LEVEL

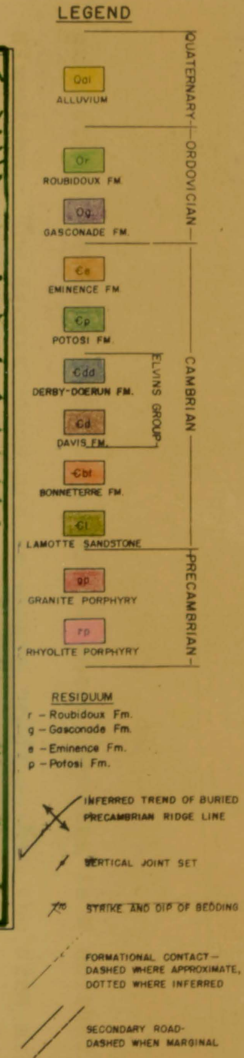
FIGURE 30



JOHNSON'S SHUT-INS STATE PARK 1-1/2 MILES
UNION ELECTRIC CO. UPPER RESERVOIR
CENTERVILLE 9 MILES
TAUM SAUK CUT
UNION ELECTRIC CO. CONSTRUCTION SITE
17
16
19
20
21
30
29
28
Qal
rp
gp
€p
€dd
€d
LEGEND
QUATERNARY
ORDOVICIAN
CAMBRIAN
PRECAMBRIAN
ELVINS GROUP
ALLUVIUM
ROUBIDOUX FM.
GASCONADE FM.
EMINENCE FM.
POTOSI FM.
DERBY-DOERUN FM.
DAVIS FM.
BONNETERRE FM.
LAMOTTE SANDSTONE
GRANITE PORPHYRY
RHYOLITE PORPHYRY
RESIDUUM
r – Roubidoux Fm.
g – Gasconade Fm.
e – Eminence Fm.
p – Potosi Fm.
INFERRED TREND OF BURIED PRECAMBRIAN RIDGE LINE
VERTICAL JOINT SET
STRIKE AND DIP OF BEDDING
FORMATIONAL CONTACT – DASHED WHERE APPROXIMATE, DOTTED WHERE INFERRED
SECONDARY ROAD- DASHED WHEN MARGINAL
BASE FROM U. S. GEOLOGICAL SURVEY TOPOGRAPHIC SHEET EDGEHILL, MO. 15' QUADRANGLE TOWNSHIP 33 NORTH, RANGE 2 EAST
CONTOURS FROM BASE PREPARED BY SURDEX CORPORATION FOR UNION ELECTRIC COMPANY, TAUM SAUK PROJECT
GEOLOGIC MAP OF THE
TAUM SAUK AREA
REYNOLDS COUNTY, MISSOURI
500 0 500 1000 1500 2000 2500 FEET
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

FIGURE 31





TOTAL INTENSITY AEROMAGNETIC MAP OF THE TAUM SAUK AREA

CONTOUR INTERVAL 10 GAMMAS

FROM TOTAL INTENSITY AEROMAGNETIC MAP OF EDGEHILL QUADRANGLE, MISSOURI

(MISSOURI GEOLOGICAL SURVEY, ROLLA, MISSOURI, 1961)

FLIGHT ELEVATION: 2,000 FEET ABOVE SEA LEVEL

FIGURE 30

101a

accessible by Missouri Route M, which crosses the area in a northerly direction. The access roads and secondary roads within the area are well maintained and generally in good condition.

PREVIOUS WORK

The Taum Sauk area was previously mapped by C. L. Dake (1930) at a scale of 1:62500. Anderson and Scharon (1961) completed a preliminary study of petrology and structure of igneous rocks in the vicinity of the Taum Sauk area. O'Brien (1961) reports results of exploratory drilling at Union Electric's Taum Sauk project, and offers a brief discussion of local geology. No other work has been published on the area.

GEOLOGIC SETTING OF THE AREA

The higher ridges of the Taum Sauk area consist of rhyolite porphyry and granite porphyry. These high ridges owe their present configuration partly to sub-aerial erosion in Precambrian time. They were subsequently partly or completely buried by Cambrian and Ordovician sediments. The ridges have been extensively resurrected by a long sub-aerial erosion cycle which is thought to have persisted from Pennsylvanian time until the present. Sedimentary rocks of the Potosi, Derby-Doerun, and Davis formations crop out in the valleys between the high Precambrian ridges. No faults are recognized in the area.

Geomorphology

The Taum Sauk area has high relief. The greatest elevation in the area, 1,530 feet above sea level, is at the crest of a high granite porphyry ridge along the eastern boundary of the area. The lowest elevation, in the stream bed of the East Fork of the Black River, is about 730 feet above sea level. Total relief is 800 feet.

Drainage within the area is largely controlled by Precambrian topography. Walker Branch and a southward flowing tributary in section 20 generally parallel Precambrian ridges. They in turn empty into the East Fork of the Black River, which flows parallel to the high southward trending granite porphyry ridge. These may be classified as subsequent streams, and appear in part to be following drainage trends established in Precambrian and Early Cambrian time.

The granite porphyry and rhyolite porphyry in the eastern part of the area have the steepest slopes and greatest relief. Lower hills within the area are capped by the Potosi Formation and residuum of the Gasconade Formation.

STRATIGRAPHY OF EXPOSED FORMATIONS

Five mappable rock units are present in the Taum Sauk area, including rhyolite porphyry and granite porphyry of Precambrian age. The three sedimentary rock units are of late Cambrian age. The Davis Formation is the oldest sedimentary unit in the map area, and is extensively exposed in stream beds and at lower elevations. The Derby-Doerun Formation crops out less abundantly, and at intermediate elevations. The Potosi Formation is at relatively higher elevations in the area, and rarely crops out. Its presence is indicated by abundant quartz druse float. Igneous rocks crop out extensively, particularly along the eastern boundary of the area, and generally underlie the highest hills.

A thick residual mantle, consisting primarily of chert from the Gasconade Formation, covers much of the area.

Rhyolite Porphyry

The lower portion of the west slope of the high ridge along the eastern boundary of the area is underlain by rhyolite porphyry. This rock extends northwestward into the area of Johnson Shut-ins State Park. It is exposed extensively at Johnson Shut-ins, immediately north of the Taum Sauk area. Rhyolite porphyry also crops out extensively in the north half of section 29, in the south-central part of the Taum Sauk area. This rock has an aphanitic, dark red to purple groundmass, with enclosed euhedral to subhedral phenocrysts of glassy quartz and white to pink orthoclase feldspar. The phenocrysts range to about 4 mm. The feldspar is extensively altered to kaolinite. The rock commonly breaks down into angular fragments, which appear fresh, even after long weathering. A more detailed study of this rock has been completed by G. A Muilenburg (1930, p. 30).

Granite Porphyry

The upper portion of the high ridge along the eastern boundary of the area is underlain by granite porphyry. A previously unmapped Pre-cambrian exposure in the south-central part of section 19 also consists of granite porphyry. This rock has a fine to medium crystalline, pale red to pink groundmass composed of orthoclase feldspar. Phenocrysts of feld-spar and glassy quartz that are as large as 4 mm. stand out in the relatively uniform crystalline groundmass. Minor accessory minerals include biotite and magnetite. G. A Muilenburg (1930, p. 36) also describes this rock.

Davis Formation

The Davis Formation crops out extensively in the Taum Sauk area, and essentially its entire thickness is exposed in the Taum Sauk Cut (Figure 32). The formation is characterized by two distinct facies in the Taum Sauk area. In the eastern half of the area much of the formation is composed of white, coarsely crystalline dolomite, called "white rock" by miners and drillers. The formation consists predominantly of silty, fine-grained dolomite in the western half of the area.

Units of the Davis Formation in the Taum Sauk Cut are typical of the "white rock" facies. The Taum Sauk Cut was studied in detail as part of the mapping of the Taum Sauk area. The exposed rock sequence of the cut was divided into units generally of similar lithology for convenience of description.[5] Figure 32 shows the location of each of these units in the cut. Photomicrographs of oriented samples taken from selected described units are also included with the following descriptions.

Unit 1
Dolomite, light, bluish gray, coarsely crystalline; crystals subhedral to euhedral, and in random intergrown orientation; very thick-bedded, with thin seams of light, greenish blue shale along bedding planes; a few thin beds of dolomite finely crystalline..17' 6"

[5]The following classification is used in describing bedding thicknesses: beds less than three inches thick are termed thin-bedded; beds ranging from three inches to twenty four inches are termed medium-bedded; beds ranging from twenty four inches to forty eight inches are termed thick-bedded; beds more than forty eight inches are termed very thick-bedded.

Unit 2

Dolomite, light, bluish gray, finely crystalline, compact, interbedded with shale, light, greenish gray; dolomite in nodular and lenticular masses as much as two inches thick. Dolomite and shale in approximately equal thickness. Entire unit grades laterally into very thick-bedded, coarsely crystalline dolomite. Dip 10 degrees......................10' 0"

Unit 3

Dolomite, light, bluish gray, coarsely crystalline, crystals subhedral to euhedral in random intergrown orientation; few thin beds finely crystalline with vertical gradation into coarsely crystalline beds; contains few interbedded greenish blue shale seams. Dip 13 degrees.................12' 6"

Unit 4

Shale, dark, bluish gray; interbedded with dolomite, light gray, finely crystalline, compact, bedding lenticular and irregular, with irregular shale laminae. Dolomite and shale in nearly equal thicknesses. Unit laterally persistent. Dip 13 degrees................................. 4' 6"

Unit 5 (upper)

Dolomite, light, greenish gray, coarsely crystalline, crystals subhedral to euhedral, randomly intergrown, compact; light, greenish gray shale disseminated irregularly throughout rock, shale component about 15 percent. Dip 14 degrees.......... 7' 0"

Unit 5 (middle)

Dolomite, very thin to thick-bedded, irregularly stratified in fine, and medium to coarsely crystalline layers which are respectively dark and light, bluish gray; rock is compact with few zones very porous, crystals subhedral to euhedral, randomly intergrown; minor disseminated pyrite. Dip 14 degrees... 7' 0"

Unit 5 (lower)

Dolomite, light, bluish gray, medium to coarsely crystalline, crystals subhedral to euhedral, light and dark gray, partly irregular stratification lines similar to varves, minor disseminated pyrite and rhyolite porphyry fragments, ranging from 1/16 to 1/4 mm. diameter. Dip 14 degrees.............13' 6"

Unit 6

Shale, light green, slightly calcareous; with persistent central bed of dolomite, light gray, medium crystalline, nodular, twelve inches thick, with included irregular lenses of light green shale. Unit about 60 percent shale, 40 percent dolomite. Dip 14 degrees................................. 3' 0"

Unit 7
Dolomite, light, bluish gray, fine to medium crystalline, with coarsely crystalline zones, vague irregular lines of stratification, compact, thick-bedded; few thin laminae of green shale; dolomite contains minor detrital quartz, rhyolite porphyry, and disseminated pyrite. Dip 14 degrees.. 8' 0"

Unit 8 (upper)
Dolomite, light gray, coarsely crystalline; crystals, subhedral to euhedral, randomly intergrown, unit is medium-bedded. Shale, light green, dolomitic, weakly fissile, lenticularly bedded and nodular, compact. Unit 60 percent dolomite, 40 percent shale. Dip 14 degrees....... 4' 0"

Unit 8 (middle)
Dolomite, light gray, medium crystalline, crystals subhedral to euhedral, randomly intergrown; rock compact to porous, thin-bedded; few one inch dark green shale seams, few vague lines of stratification, scattered euhedral pyrite.
Dip 14 degrees.. 2' 0"

Unit 8 (lower)
Dolomite, light gray, coarsely crystalline, medium-bedded; shale, light green, irregularly bedded, lenticular and nodular, compact. Dolomite 60 percent, shale 40 percent.
Dip 14 degrees.. 5' 0"

Unit 9
Dolomite, light gray, medium crystalline, crystals subhedral to euhedral, randomly intergrown; rock compact to partly porous and vuggy, thin to medium-bedded, few vague irregular lines of stratification, few thin light green shale seams.
Dip 14 degrees.. 7' 6"

Unit 10
Shale, dark green, dolomitic, poorly stratified, lenticularly bedded and nodular, compact. Dolomite, light gray, very coarsely crystalline, very porous and vuggy; vugs very irregular and filled with light green shale. Shale 65 percent, dolomite 35 percent. Dip 14 degrees................ 3' 9"

Unit 11
Dolomite, thin to medium-bedded, alternating light and medium gray beds, with few beds pink. Medium gray beds coarsely crystalline; light gray and pink beds medium crystalline; few thin green shale seams; dolomite crystals subhedral to euhedral, randomly intergrown. Dip 16 degrees..............17' 6"

Unit 12

Dolomite, light gray to pink, thin to thick-bedded; medium to coarsely crystalline, moderately porous; irregularly interbedded with light green, dolomitic shale. Dolomite crystals subhedral to euhedral, randomly intergrown. Dip 17 degrees.. 7' 6"

Unit 13

Dolomite, light gray to dark, greenish gray, thick-bedded, irregular thin green shale partings, very fine to medium crystalline; fine, light and dark gray stratification lines present which resemble varves; euhedral pyrite and few scattered calcite inclusions. Dip 19 degrees...........22' 9"

Unit 14

Dolomite, pink, medium to finely crystalline, medium-bedded with partly irregular bedding planes, abundant detrital quartz and rhyolite porphyry fragments ranging from ¼ to 1 mm. in diameter. Interbedded with shale, light green, poorly stratified, dolomitic. Dolomite 50 percent, shale 50 percent. Dip 31 degrees..37' 0"

Total section in Taum Sauk Cut..................................190' 0"

The Davis Formation of the western half of the Taum Sauk area is best exposed in outcrops adjacent to Missouri State Route M. An outcrop in the center of the southwest quarter of section 20 is shown in Figure 39. A description of this outcrop follows:

Dolomite, light brown, dark brown on weathered surfaces, fine to medium-grained, silty, argillaceous, partly cherty, with chert nodules present along bedding planes; thin to medium-bedded, locally cross-bedded. Cross-bedding indicates a northerly source for the clastic material................. 5' 0"

An outcrop of the Davis Formation adjacent to Missouri Route M, near the northeast corner of section 30 is as follows:

Dolomite, light brown, dark brown on weathered surfaces, fine to medium-grained, silty and argillaceous, partly cherty; angular rhyolite porphyry fragments as much as 6 mm. in diameter comprise about 15 percent of the rock; unit medium to thick-bedded.. 5' 0"

TAUM SAUK CUT–UNION ELECTRIC COMPANY

NORTH WALL OF TAILRACE

SE SW SECTION 21, T33N, R2E, REYNOLDS COUNTY, MISSOURI

SHOWING

LITHOLOGIC UNITS OF THE DAVIS FORMATION AS DESCRIBED IN THE DISSERTATION AND THEIR RELATIONSHIP TO BURIED PRECAMBRIAN TOPOGRAPHY

EAST

SCALE: 1 INCH EQUALS APPROXIMATELY 25 FEET

FIGURE 32

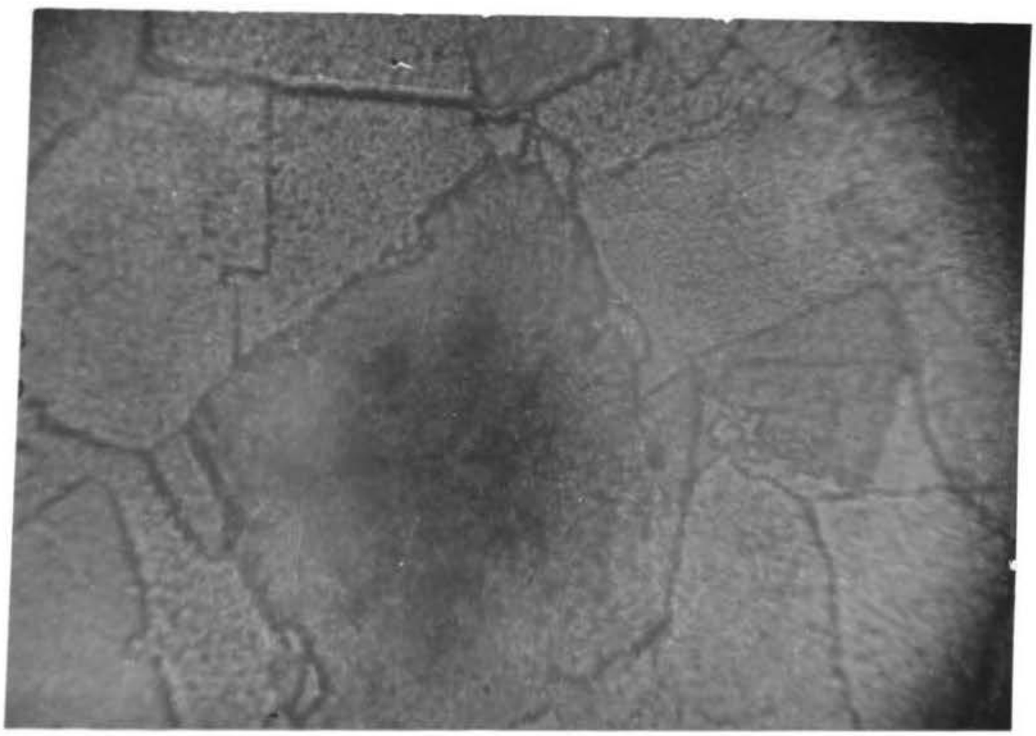


Figure 33. Unit 1. Coarsely crystalline inequigranular dolomite mosaic. Dark ovoid patch in rhomb at center of field may be relict organic structure. Dolomite euhedra are generally intergrown. (47X)

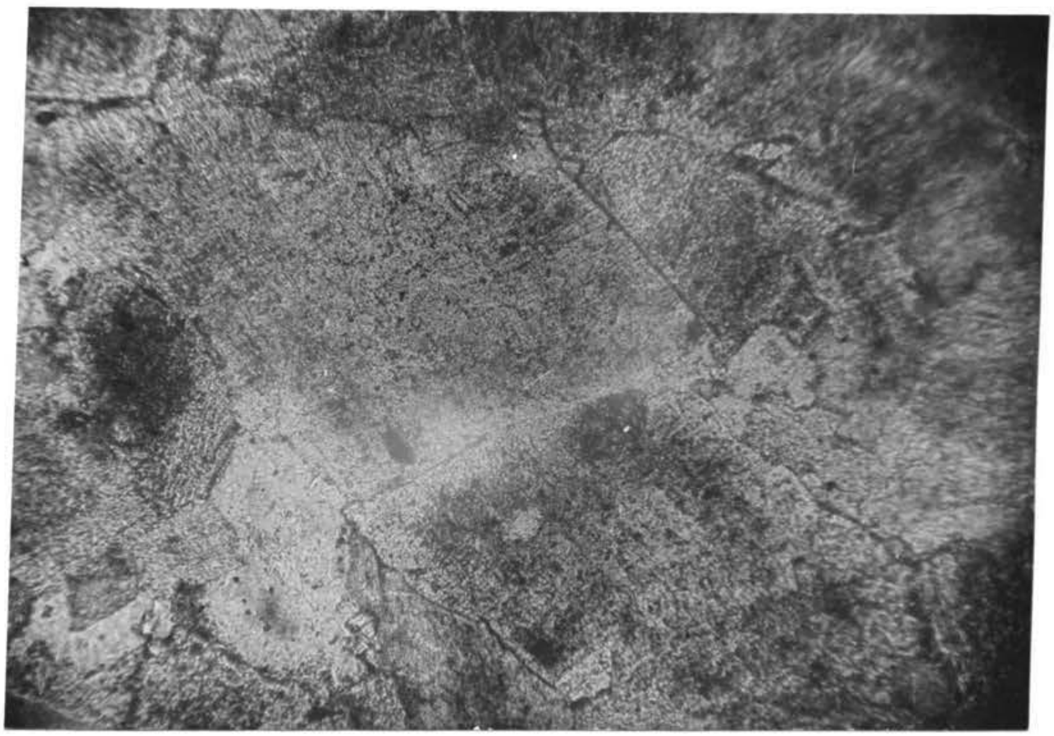


Figure 34. Unit 5 (middle). Inequigranular dolomite mosaic, with few specks disseminated pyrite. Rhombs are imperfectly shaped and strongly intergrown. Dark oval patch near left edge of field may be relict organic structure. (47X)

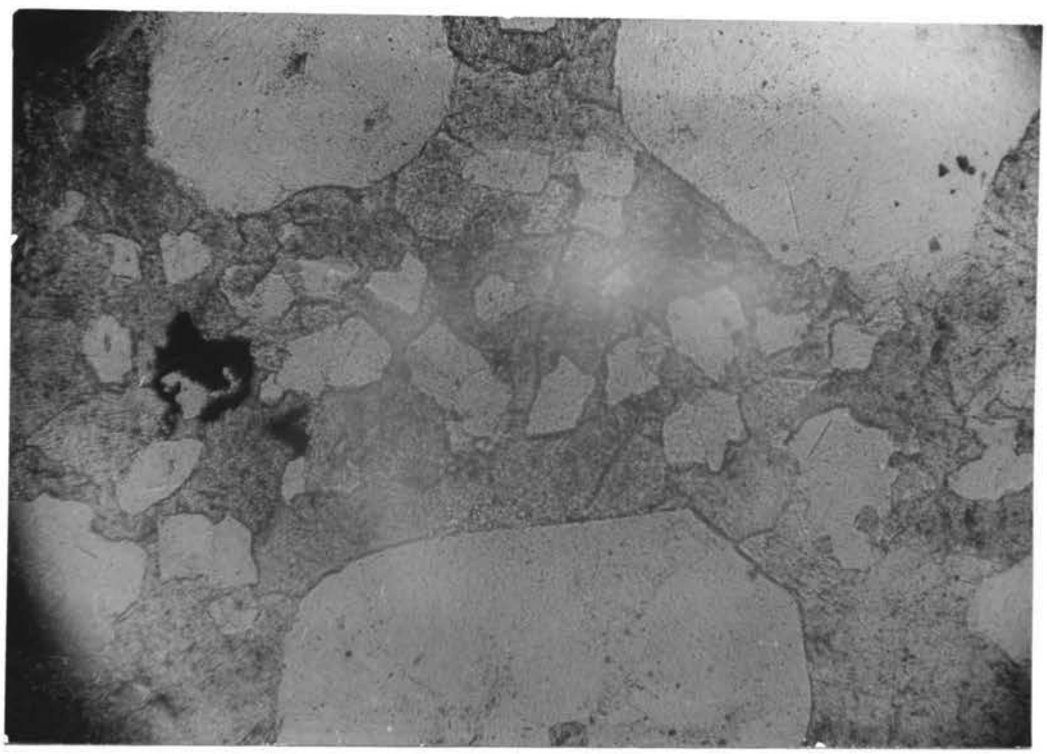


Figure 35. Unit 7. Angular and subrounded detrital quartz grains in fine-grained to microcrystalline dolomite mosaic. Small quartz grains are much more angular and occur in a zone extending across center of field. Individual quartz grains are entirely separated by dolomite, and may be locally partly replaced by dolomite. (47X)

Figure 36. Unit 9. Inequigranular dolomite mosaic. Dolomite euhedra and anhedra show typical random intergrowth. Dark shading and patches in lower part of field may be of organic origin. (47X)

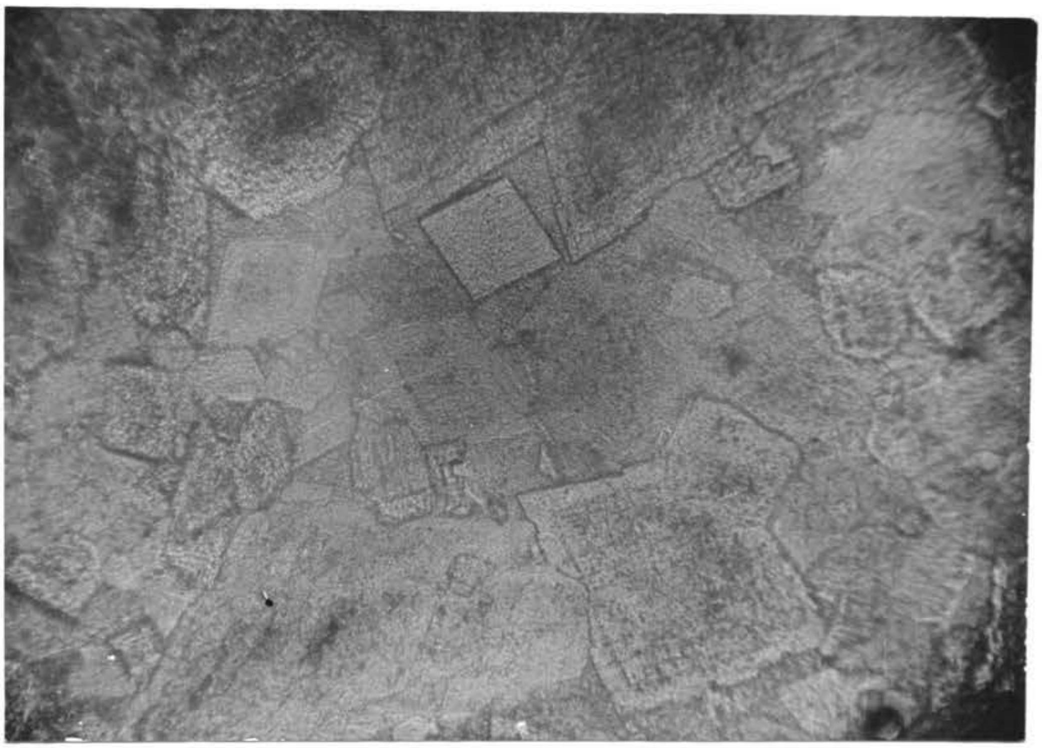


Figure 37. Unit 11. Inequigranular dolomite mosaic. Several nearly perfect dolomite rhombohedra are present in the center of field. Darker central zones are present in several of the crystals. Some show distinct secondary enlargement. (47X)

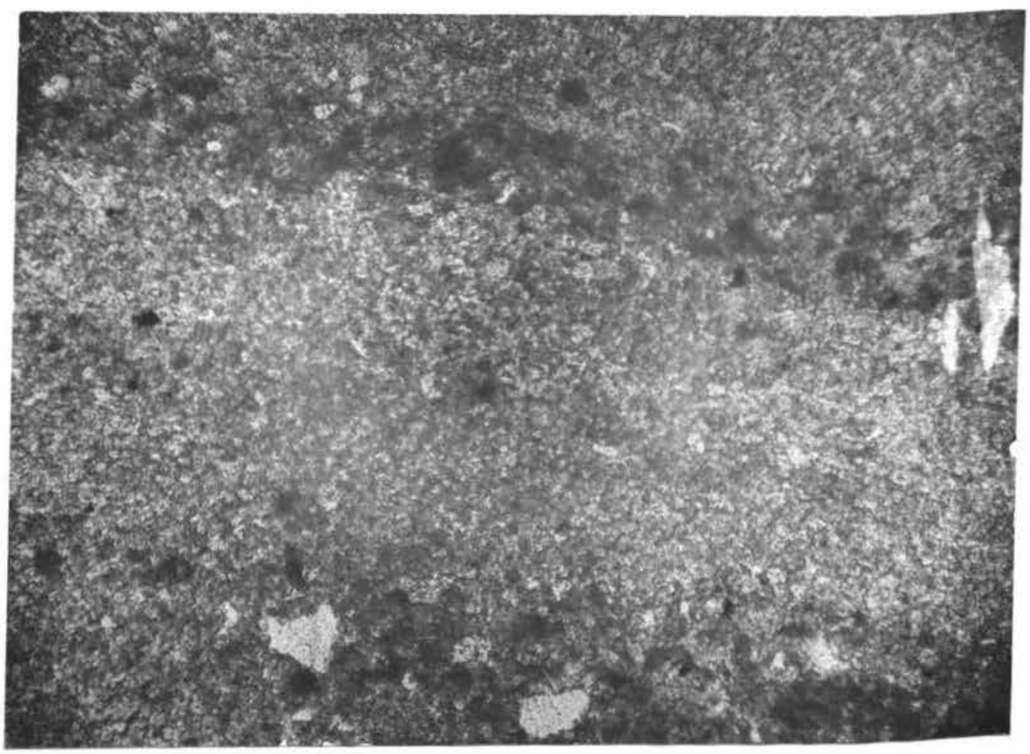


Figure 38. Unit 13. Alternation of very finely crystalline and crypto-crystalline dolomite laminae. Scattered, very fine-grained detrital quartz in dark laminae. Dark specks are authigenic pyrite. Megascopically this rock resembles a varved mudstone. (47X)

Figure 39. Cross-bedding in this clastic unit is easily visible here. A northerly source for the carbonate detritus is indicated (north is to right of photograph). This rock has a granular, silty texture. (Center, SW¼, section 20).

Sedimentary characteristics of the above outcrops indicate a clastic origin. The rocks appear to be dolomitized calcarenites. The angularity of the rhyolite porphyry fragments at the second outcrop suggest a local source for the detrital material. This material probably came from the large rhyolite porphyry knob immediately east of the outcrop.

Derby-Doerun Formation

The Derby-Doerun Formation is very similar in lithology to the Davis Formation in the Taum Sauk area. In the eastern part of the area it is predominantly white, coarsely crystalline dolomite or "white rock". In the western part of the area it is thin to medium-bedded dolomite, largely finely crystalline, and partly silty and shaly. Good exposures of the Derby-Doerun Formation are in the NE¼, NW¼ of section 30, in a small stream gulley. An outcrop at this location consists of:

Dolomite, light to medium gray, dark brown to black on weathered surfaces, finely crystalline, dense, thin to medium-bedded, faint relict oolite structure. Strike N. 25°W., Dip 10° Northeast.. 5' 0"

Figures 40 and 41 are photomicrographs of a thin section of the rock. The oolites occur in zones and thin irregular layers adjacent to areas of very finely crystalline dolomite. Their average diameter is about 0.1 mm. Crystals within many of the oolites have crudely concentric arrangement, particularly at the outer margins. This may reflect original concentric layering of the oolites before dolomitization. Faint, rounded outlines similar in size to that of the visible oolites occur over most of the thin section. This suggests that the rock originally may have

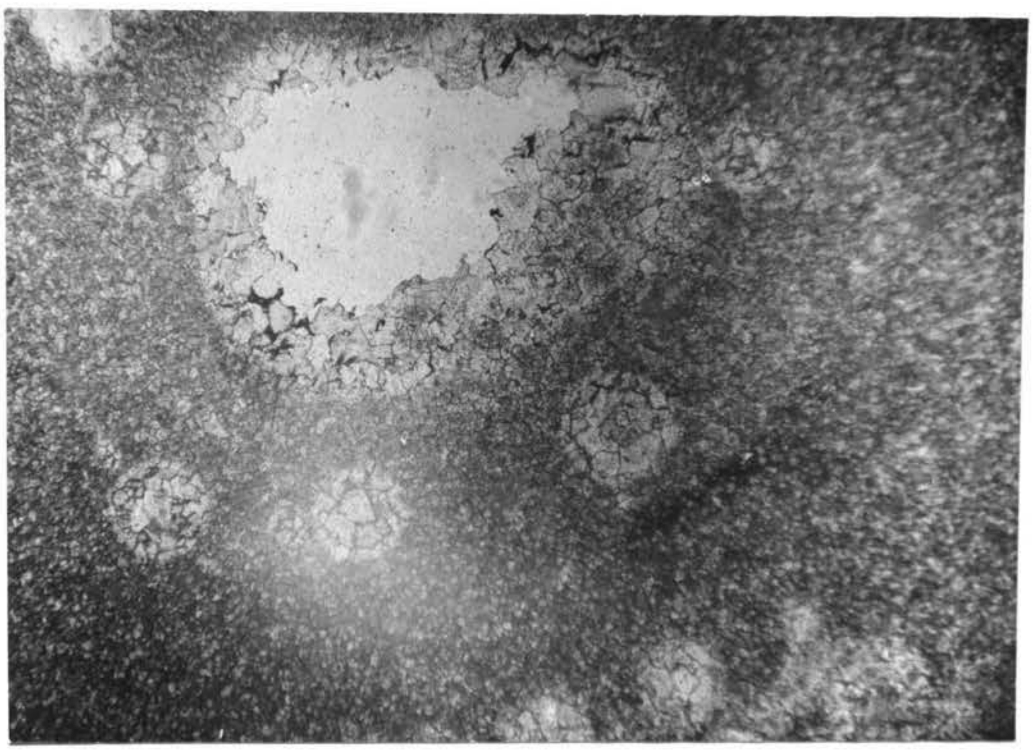


Figure 40. Oolitic dolomite of the Derby-Doerun Formation. Note crudely concentric arrangement of outermost dolomite anhedra in oolite at lower right of center of field. Large oval, and partly chipped-out body at center of field may be of oolitic origin. (47X)

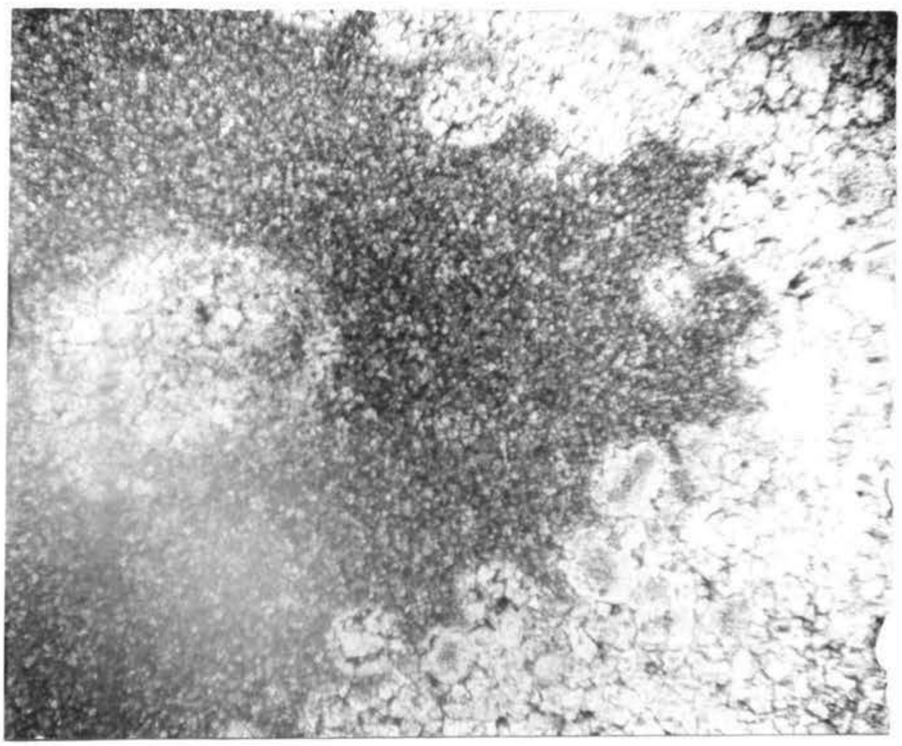


Figure 41. Rounded and oval oolites adjacent to a darker area of very finely crystalline dolomite; numerous faint rounded outlines in the lighter, finely crystalline dolomite. Latter may be oolites largely obscured by dolomitization. (47X)

been predominantly oolitic. Much of the oolitic texture may have been obscured by dolomitization.

Potosi Formation

Because of a thick residual mantle over many hills, outcrops of the Potosi Formation are rare in the Taum Sauk area. However, the occurrence of characteristic quartz druse float at the surface suggests its presence.

The formation is generally thick-bedded, in contrast to the generally thin-bedded and shaly units of the underlying Derby-Doerun Formation. An outcrop of the Potosi Formation near the center of the north line of section 30 shows:

Dolomite, dark brown, dark brown to black on weathered surfaces, finely crystalline, dense, thick-bedded; scattered quartz druse float near outcrop.. 3' 0"

The lower thirty feet of the Potosi Formation near the crest of the hill in the southeast quarter of section 20 consists of typical white, coarsely crystalline dolomite, or "white rock" previously described in the Davis and Derby-Doerun Formations. Outcrops stratigraphically higher were not observed in the eastern part of the Taum Sauk area.

Residuum of the Gasconade Formation

The Gasconade Formation is not exposed in the Taum Sauk area. Thick accumulations of residual material from this formation blanket the lower hills and ridges in the area. Where exposed by excavation or stream erosion, the residuum has definite bands and layers resembling stratification (Figure 42). This suggests that the residuum represents

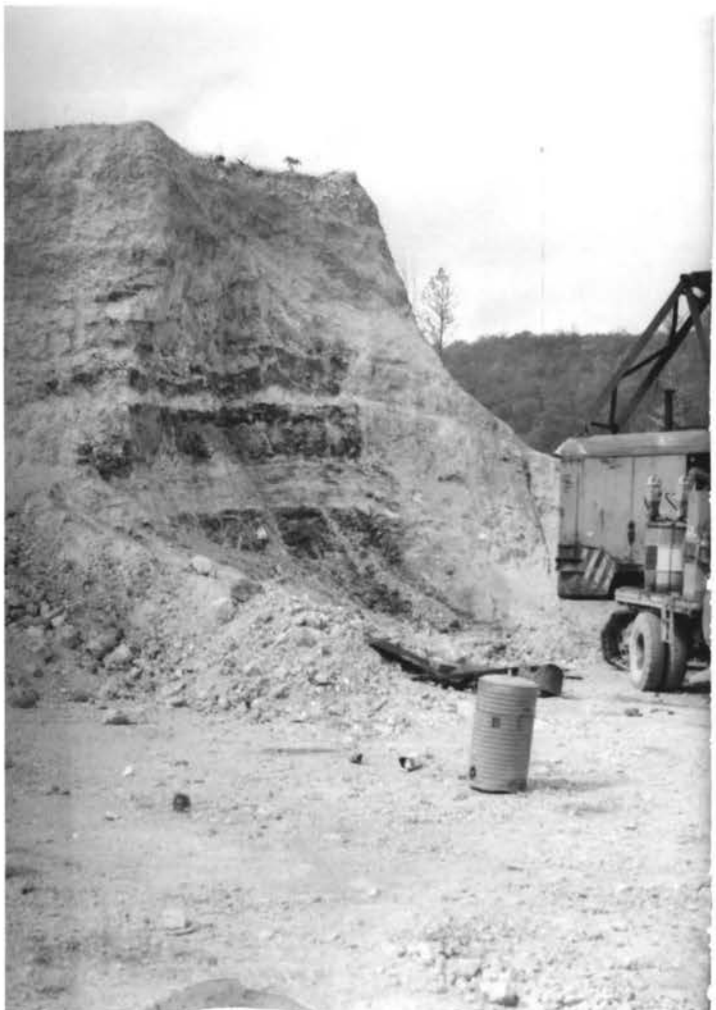


Figure 42. Stratified chert and clay residuum of the Gasconade Formation. This residual material mantles most hills and slopes of the Taum Sauk area. (Center, north line of section 28, T. 33 N., R. 2 E.).

essentially the in situ insoluble residues of the formation.

Quaternary Surficial Deposits

Alluvial clay, silt, sand, and gravel occur in the flood plain of the East Fork of the Black River in the southeastern part of the Taum Sauk area. These attain a thickness of about twenty feet near the center of the flood plain. Elsewhere within the area streams generally flow directly upon bedrock.

DEPOSITIONAL ENVIRONMENTS OF THE TAUM SAUK AREA

Sedimentary rocks of the Taum Sauk area include thick-bedded, white, coarsely crystalline dolomite, dark brown, thin-bedded and silty dolomite, and dark green, partly dolomitic shale. Accessory constituents of these rocks include detrital quartz and feldspar, and rhyolite porphyry fragments. Sedimentary features that give indication of environment of deposition are oolites, cross-bedding, detrital material, and lines of stratification resembling varves. The brachiopod genus Eoorthis is known at two localities within the area in the upper part of the Davis Formation. No other fossil remains were identified in the area.

Eastern Half of Taum Sauk Area

White, porous, coarsely crystalline dolomite is the dominant lithology in the eastern half of the Taum Sauk area. This rock occurs interbedded with subordinate dark green dolomitic shale through a vertical stratigraphic interval of more than 350 feet. The white dolomite transgresses formational boundaries of the Davis, Derby-Doerun, and Potosi

Formations. Some phases of the rock display an alternation of very finely crystalline dolomite and darker crypto-crystalline dolomite laminae that resemble varves (Figure 38). These laminae are parallel and almost perfectly planar. The extensive intergrowth of generally well-formed dolomite rhombs is a notable characteristic of the rock.

The composition and texture of this white, crystalline dolomite at the time of its deposition is a matter of uncertainty. The finely crystalline phases in the Taum Sauk Cut commonly contain detrital materials, suggesting a clastic origin. The fine, detrital material (detrital calcite, quartz, feldspar, and rhyolite porphyry fragments) may have interfered with, and thus restricted the growth of large dolomite crystals. No detrital materials were identified in the coarsely crystalline phases of the rock. The writer believes the coarsely crystalline dolomite was originally a lime mud of high purity, that contained no clastic impurities to interfere with the growth of large well-formed crystals. The rock probably was deposited in a quiet water environment where only limited clastic reworking occurred.

The dark green, partly dolomitic shale is intimately interbedded with white crystalline dolomite. In the Taum Sauk Cut the shale, in some instances, grades laterally into dolomite over short distances. In Unit 10 of the Taum Sauk Cut (Figure 32), the dolomite is porous and vuggy, and the vugs are filled with light green shale. Much of the shale in this unit is lenticularly interbedded with dolomite. The alternating sequence of green shale and dolomite, as seen in Units 7 through 14 (Figure 32), suggests rhythmic changes in depositional environment.

Whether the lime mud is an organic or inorganic precipitate is presently unknown. If it be organic, intensive dolomitization has destroyed evidence relating to the organic processes involved. The green, dolomitic shale may have been deposited during times when the nearby igneous terrain was subjected to profound chemical weathering (Figure 48). The shale may be the final weathering product in this process.

Western Half of Taum Sauk Area

Dark brown, thin-bedded dolomite is the dominant lithology in the western half of the Taum Sauk area. This rock is largely silty and granular. This type of lithology is found in the Davis, Derby-Doerun, and Potosi formations; these units are generally similar in lithologic character, although the Potosi Formation is more massively bedded. At various localities these units contain large fragments of detrital feldspar, are cross-bedded, and are partly oolitic. These features indicate a clastic origin for these rocks. The size of the detrital feldspar fragments (up to 6 mm.) and the cross-bedding suggests a high agitation aqueous environment. Some of these units must have been deposited at or near wave base.

Brachiopods of the genus Eoorthis are identified at two localities within the western portion of the area. Mainly intact dorsal and ventral valves of Eoorthis were observed, suggesting little or no reworking of this horizon.

The strongly contrasting sedimentary rock types suggest markedly different environments of sedimentation in the eastern and western parts of the Taum Sauk area during Davis, Derby-Doerun and early Potosi times. Moderately vigorously agitated waters must have prevailed in the western part of the area during this time. For the eastern half of the area, the nearly complete absence of detrital material except closely adjacent to Precambrian hills, the even varve-like laminae within the crystalline dolomite, and the abundance of shale suggest deposition in relatively quiet water.

Considering the presently exposed Precambrian topography of the area, it is possible to postulate sedimentation conditions which developed these strongly contrasting, but closely adjacent depositional environments. The high Precambrian ridge which extends around the northeastern margins of the Taum Sauk area ranges from 1,100 feet to more than 1,500 feet above sea level, and must have stood somewhat higher in Late Cambrian time. Cross-bedding, oolites, and detrital feldspar of the Davis and Derby-Doerun Formations occur at an elevation of about 800 feet above sea level, or at least 300 feet below the present crest of the Precambrian ridge. Thus it is probable that the ridges existed as land masses or islands in Late Cambrian seas and formed a partial barrier to open circulation of sea water eastward. A somewhat lower Precambrian ridge, now partly buried, exists along the southern boundary of the area; this probably served to restrict sea water circulation. Thus the partly exposed Precambrian topography suggests an environment of restricted circulation in the eastern part of the Taum Sauk area during Late Cambrian time. Westward the area may have been completely open; here clastic carbonate sediments predominate.

BOULDER CONGLOMERATE OF TAUM SAUK TUNNEL

In excavating a tunnel eastward into rhyolite porphyry at the east end of the Taum Sauk Cut, workers again encountered dolomite at a distance of about 600 feet from the tunnel opening. At this point the formation was found to contain a number of unweathered to deeply weathered angular and rounded boulders of rhyolite porphyry. After passing through dolomite for about 800 feet, the tunnel encountered granite porphyry and remained in igneous rock throughout the remainder of its course.

This interval of sedimentary rock apparently was a small ravine formed by Precambrian stream erosion at the contact between granite porphyry and rhyolite porphyry. The ravine was filled with sediments of the Davis Formation during Late Cambrian time. The boulders encased in the sediments apparently fell from the rhyolite porphyry ridge to the west during deposition of the Davis Formation. All boulders observed are composed of rhyolite porphyry, and are within seventy five feet of the rhyolite porphyry ridge.

Figure 43 shows the location at which the tunnel passes from rhyolite porphyry into finely crystalline dolomite of the Davis Formation. Of particular interest is the steep dip of bedding adjacent to the rhyolite porphyry ridge. The beds become horizontal at a distance of about three feet from the rhyolite porphyry. Note also the somewhat irregular bending of bedding planes around the encased boulders.

Figure 44 overlaps the lower part of Figure 43, and shows a number of angular, apparently unweathered rhyolite porphyry boulders in various positions, and completely enclosed in dolomite. The photograph again reveals the somewhat irregular bedding of the dolomite. Note the sharp bending of bedding planes around the upper right corner of the large boulder in the center of the photograph.

The eastern margin of a very large boulder exposed near the top of the tunnel, about thirty feet east of the rhyolite porphyry ridge, is shown in Figure 45. Once more the steep dip of bedding is adjacent to the nearly vertical flank of the rhyolite porphyry boulder. The dip of the bedding here locally exceeds 50 degrees.

The lower portion of Figure 45 is overlapped by Figure 46, and shows the lower portion of the large rhyolite porphyry boulder. Smaller fragments have become separated from the boulder, and appear almost "arrested in motion" by the enclosing dolomite. Note the slight irregularities of bedding around even these smaller fragments.

Figure 47 is about fifty feet east of the rhyolite porphyry ridge and shows strong bending of bedding planes over the crest of a medium-sized boulder. Here, bedding dips at a maximum angle of 60 degrees. The lower part of the exposure is again obscured by splattered mud.

Figure 48, about sixty feet east of the western-most rhyolite porphyry ridge, shows irregular bending of bedding around a number of deeply weathered rhyolite porphyry boulders. The bedding closely follows the upper surfaces of the two boulders in the lower half of the picture, but dips downward slightly between the two boulders. These boulders apparently underwent long sub-aerial weathering prior to burial.

In exposures in the Taum Sauk tunnel, bedding of finely crystalline dolomite of the Davis Formation displays unusually high dips and a

Figure 43. Location at which tunnel passes from rhyolite porphyry into dolomite of the Davis Formation. Dark red rock at right is rhyolite porphyry. (Scale: 1 inch equals about 3 feet).

Figure 44. Boulders of unweathered rhyolite porphyry completely enclosed in dolomite. Note generally disordered arrangement of boulders. (Scale: 1 inch equals about 3 feet).

Figure 45. Eastern margin of a large rhyolite porphyry boulder, showing steeply dipping bedding of adjacent sediments. (Scale: 1 inch equals about 3 feet).

Figure 46. Lower portion of large rhyolite porphyry boulder shown in Figure 45. Lower part of exposure is obscured by mud splattered by excavation vehicles. (Scale: 1 inch equals about 3 feet).

Figure 47. Bedding here bends strongly around the enclosed rhyolite porphyry boulder. Bedding dips at an angle of 60 degrees. (Scale: 1 inch equals about 3 feet).

Figure 48. Deeply weathered rhyolite porphyry boulders about sixty feet east of the rhyolite porphyry ridge. (Scale: 1 inch equals about 3 feet).

bending or draping effect over the enclosed rhyolite porphyry boulders. These dips and associated features are clearly not of tectonic origin. No faults are recognized within the Taum Sauk area, and local evidence of tectonic movement is entirely lacking.

The characteristics of the beds and enclosed boulders suggest a depositional or post-depositional origin. Three processes are known that may have wholly or in part contributed to the development of these features: initial dip, solution, and differential compaction.

Initial dip implies that any dip that the sediments display is caused by the slope of the surface upon which they were deposited, except where altered by deformational processes. Initial dip is defined in the "Glossary of Geology and Related Sciences" (American Geological Institute, 1960, p. 149) as:

> The angle of slope of bedding surfaces at the time of deposition, the contacts between layers usually being approximately parallel with the surface of deposition unless subsequently altered by differential compaction or other deformational processes.

An important factor bearing upon initial dip is the angle of repose that unconsolidated sediments are able to maintain without slumping. According to Lahee, (1952, p. 299),

> The maximum angle of repose for coarse gravels is about 35 degrees. Even 42 degrees has been recorded.......when well soaked with water, mud and clay may slide on slopes of only 2 degrees or 3 degrees.

Extensive sliding of unconsolidated and partly lithified lime muds has been reported by Snyder and Odell (1958, p. 918) in the Bonneterre Formation on slopes as low as 4 degrees.

In consideration of these factors, it appears unlikely that the high dips and the bending or draping effect over and adjacent to the rhyolite porphyry boulders is due to initial dip.

Partial solution of sediments after deposition could conceivably produce the above phenomena. The sediments observed within the tunnel have a low porosity, and though their attitudes vary, have nearly uniformly parallel bedding planes. Solution requires that substantial amounts of water be circulated through the rock material. The low permeability of the sediments of the tunnel appear to preclude the possibility of substantial interstitial circulation. Solution does not normally act uniformly, but opens vugs and even caverns in rock. These cavities are subject to subsequent collapse, with resultant distortion of bedding planes. The low porosity and almost perfectly regular bedding planes of the tunnel sediments appear to deny the possibility of solution origin for the observed features.

Differential compaction is the third process to be considered. Dake and Bridge (1932) believe that lime muds undergo only very limited compaction. They believe that lime muds of the Cambro-Ordovician sequence in Missouri are very similar to carbonates now being deposited on the Bahama Banks. In carefully controlled experiments, Terzaghi (1940) shows that lime mud samples from the Bahama Banks undergo almost as much compaction as argillaceous muds. Snyder and Odell (1958) show that the numerous sedimentary breccias of the Bonneterre Formation are associated with very substantial compaction of lime muds.

The unusually high dips and the bending or draping effect over and adjacent to rhyolite porphyry boulders are essentially identical to features known to be due to differential compaction. The works cited above offer convincing evidence that lime muds do indeed undergo extensive compaction during diagenesis. The writer believes that the observed features are the result of compaction of lime mud around and adjacent to the rhyolite porphyry boulders.

STRUCTURE OF THE AREA

The Taum Sauk area is characterized by unfaulted, nearly flat-lying sedimentary rocks which display dips up to 30 degrees adjacent to Precambrian topography. The marked increase in dip measured at the Taum Sauk Cut is presented graphically in Figure 49. Less than 100 vertical joints were observed in the sedimentary rocks of the Taum Sauk area. These occur primarily in the stream bed of Walker Branch, and in adjacent tributaries. These joints, in large part, show a tangential relationship to exposed Precambrian topography.

Peripheral Dips

Figure 49 shows graphically the increase in dip of sedimentary rocks of the Taum Sauk Cut as the Precambrian rhyolite porphyry ridge is approached. At a distance of 400 feet from the Precambrian ridge, the dip is 13 degrees. At 200 feet from the ridge the dip increases only one degree to 14 degrees. At 100 feet from the Precambrian ridge the dip increases 2 degrees, to 16 degrees. At this point, about 100 feet from the Precambrian ridge, very substantial increases in dip occur. In the interval from 100 feet to fifty feet, the dip increases from 16 degrees to 19 degrees. Within fifty feet from the Precambrian ridge the dip increases 12 degrees to its maximum of 31 degrees. At this point of maximum dip, the Precambrian ridge slopes at 45 degrees.

The rocks show a slow and linear increase in dip in the distance from 400 feet to 200 feet from the ridge. The interval from 200 feet to fifty feet is a transition zone where the dip changes from a slow increase to a very rapid increase. In the final fifty feet, a rapid and again linear increase in dip occurs. This zone of transition or "hinge line" is very clearly seen in the vicinity of Unit 11 in Figure 32, and in Figure 83.

High dips in the sedimentary rocks also occur near the northeast corner of section 30. These range from 10 degrees to 18 degrees. The latter occurs within 200 feet of a rhyolite porphyry ridge. At this point rocks of the Davis Formation dip generally away from the exposed Precambrian ridge and strike parallel to it.

Davis Formation outcrops with dips of 10 degrees toward the northwest and 12 degrees toward the southeast respectively, are located about 2,000 feet west of the center of section 20. These relatively high dips indicate a possible buried Precambrian ridge, trending southwestward. Other dips in excess of 10 degrees in the area may also be related to buried Precambrian topography.

Joint Patterns

A number of vertical joints in and adjacent to a stream gulley in the northeast corner of section 30 display a generally parallel or

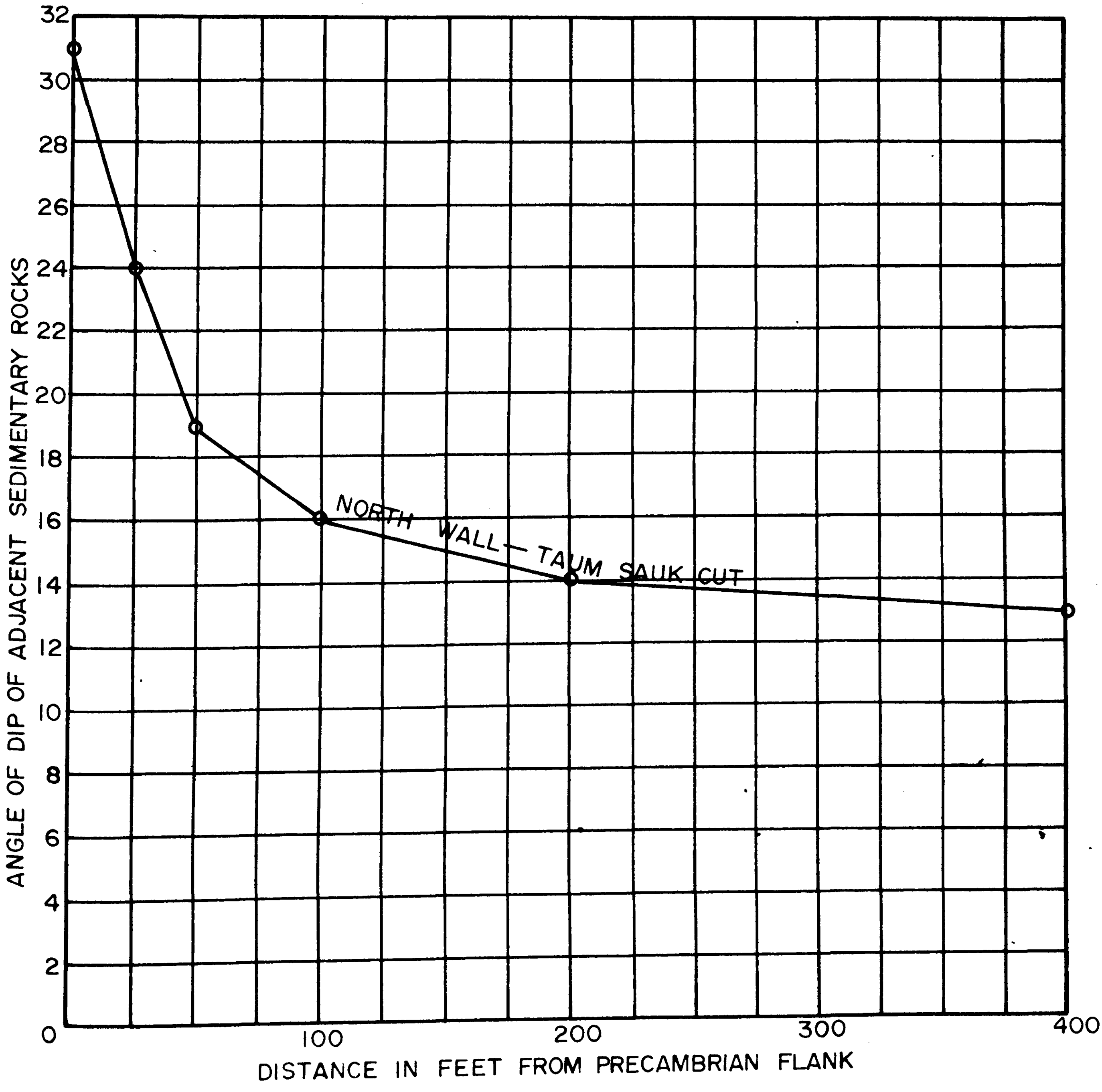


FIGURE 49. DECREASE IN ANGLE OF DIP WITH INCREASING DISTANCE FROM EXPOSED PRECAMBRIAN FLANK—NORTH WALL TAUM SAUK CUT

tangential relation to the flank of the exposed Precambrian rhyolite porphyry knob, immediately east of their location.

A second group of vertical joints, along the stream bed of Walker Branch at the north line of section 29, strike almost uniformly eastward. These show a general parallelism with the large exposed Precambrian ridge to the south.

Other joints in the southwest quarter of section 20 strike generally eastward and northward, and may have no direct relationship to buried Precambrian topography.

MAGNETIC CHARACTERISTICS OF THE AREA

Total magnetic field strength in the Taum Sauk area is about 56,700 gammas, or 0.567 gauss. The inclination of the total field is about 68° 30' (U. S. Coast and Geodectic Survey, 1955). The Taum Sauk area is included in a total intensity aeromagentic map of the Edgehill quadrangle (Missouri Geological Survey and Water Resources, 1961), flown at an elevation of 2,000 feet above sea level, and contoured with a 20 gamma contour interval. A portion of this map is shown in Figure 30.

The total intensity magnetic contours of the Taum Sauk area indicate a close correspondence of magnetic trends to the known Precambrian topography. The crest of a granite porphyry ridge near the center of the east line of section 21 is indicated on the aeromagentic map by a closed anomaly with a value of 1,354 gammas at its crest. The magnetic contours trend generally northward in the eastern part of the area, almost exactly parallel to the east flank of the high granite porphyry ridge.

A strong positive magnetic nose in the northeast corner of section 20 corresponds closely to the northwest trending rhyolite porphyry ridge in this area.

The small exposed granite porphyry knob in the south-central part of section 19 is indicated by a strong southward nosing of the magnetic contours from a closed anomaly of 1,211 gammas at its crest in the northeast corner of section 19. At the latter point, no igneous exposures correspond with the closed anomaly. It may be related to a possible buried westward extension of the exposed rhyolite porphyry ridge in the north half of section 20 (Figure 31).

SUMMARY AND CONCLUSIONS

Rock exposures of the Taum Sauk area afford an excellent opportunity to study in detail the relationship of Late Cambrian sedimentary rocks to buried and now extensively resurrected Precambrian topography.

Rocks of the Davis Formation in the Taum Sauk Cut are predominantly pure white, coarsely crystalline dolomite, and about 20 percent dark green, partly dolomitic shale. The rocks are very regularly bedded, with no indication of slump structure, and contain almost no detrital quartz of feldspar, except within a few feet of buried Precambrian topography. White, coarsely crystalline dolomite occurs in high, nearly vertical bluffs elsewhere in the eastern half of the Taum Sauk area, and is the dominant lithology.

The western half of the Taum Sauk area is characterized by thin to medium-bedded, brown, silty and argillaceous dolomite. Chert, large fragments of detrital feldspar, oolites, and cross-bedding occur in various outcrops in the western half of the area, indicating a clastic origin.

A quiet, low energy water environment is postulated for the white, coarsely crystalline dolomite of the eastern half of the Taum Sauk area. The coarsely crystalline nature of the rock suggests an original lime mud of high purity. The almost complete lack of detrital quartz and feldspar and the varve-like stratification further support a quiet water environment. Whether the lime mud has an organic or inorganic origin is unknown. If organic, all evidences of organic processes have been destroyed by dolomitization.

A clastic, shallow marine environment is postulated for the western half of the Taum Sauk area. Cross-bedding, oolites, detrital feldspar, and the silty, granular texture of the rocks support this concept.

Field relations of the sedimentary rocks to the Precambrian topography suggest an environment of restricted marine circulation in the east half of the Taum Sauk area during Late Cambrian time. The white, coarsely crystalline dolomite is believed to be the typical facies of this environment. The area is believed to have been open only to the west. Silty, cross-bedded, and oolitic dolomite is representative of the clastic, shallow marine facies of the western part of the area.

Very steep dips and irregular bending of bedding planes around boulders of rhyolite porphyry encased in finely crystalline dolomite are exposed in a tunnel extending eastward from the Taum Sauk Cut. These features are not the result of initial dip or solution. Recent work on the compaction of lime mud, and the similarity of these features to those known to be of compactional origin leads the writer to conclude that the features are the result of differential compaction of lime mud.

Increase in dip of sedimentary rocks exposed in the Taum Sauk Cut with decreasing distance from the buried Precambrian surface indicates a transition zone, where dips change from a slow linear increase to a rapid linear increase.

Vertical joints at two localities within the Taum Sauk area are generally parallel or tangent to the outline of exposed Precambrian topography. At a third locality joints strike generally eastward and northward, and may have no direct relationship to buried Precambrian topography.

A contoured total intensity aeromagnetic map of the Taum Sauk area shows very close correspondence of magnetic trends to configuration of the exposed Precambrian topography. A closed anomaly in the western part of the area does not seem related to exposed Precambrian, but it may represent a westward extension of a rhyolite porphyry ridge in the north-central part of the Taum Sauk area.

THE EMINENCE KNOB AREA

INTRODUCTION

The Eminence Knob is the western-most well exposed Precambrian knob of the Central Ozarks. It is in an important, but partly isolated area of Precambrian exposures about fifty miles southwest of extensive exposures in the St. Francois Mountains. The knob is composed of reddish brown to purple rhyolite porphyry. Its crest is 980 feet above sea level. Stratigraphic information indicates the knob extends upward through almost 1,500 feet of Late Cambrian and Early Ordovician sedimentary rocks. Only the uppermost 300 feet of the Precambrian knob has been resurrected by erosion.

Bridge (1930, p. 164) in his work in the Eminence and Cardareva quadrangles, suggests the Gunter Sandstone Member of the Gasconade Formation is a reliable marker bed in this area. He presents a 1:125000 scale structure map based on the top of this member. Bridge believes the varying elevations of the Gunter Sandstone Member indicate the approximate configuration of the underlying Precambrian surface.

In the present work an effort was made to determine the usefulness of this marker bed in detailed mapping, in order to obtain a better understanding of the partly exposed and buried Precambrian topography. The Eminence Knob area is ideal for this study because of numerous exposures of the Gunter Sandstone Member peripheral to the knob. The area also afforded the opportunity to compare the stratigraphy of this partly isolated region with that of other selected areas within the Central Ozarks.

The Eminence Knob was mapped geologically at a scale of 1:6000.

The map was later reduced to 1:24000 scale for presentation in this report (Figure 50). Strikes and dips, joints, and areal distribution of the rock formations are shown on the map.

A joint pattern analysis of vertical joints observed in the bed of a small stream east of Eminence Knob is shown in Figure 53. By use of overlapping strike diagrams the analysis shows the relationship of the strike of the joints to the exposed outline of the Precambrian knob.

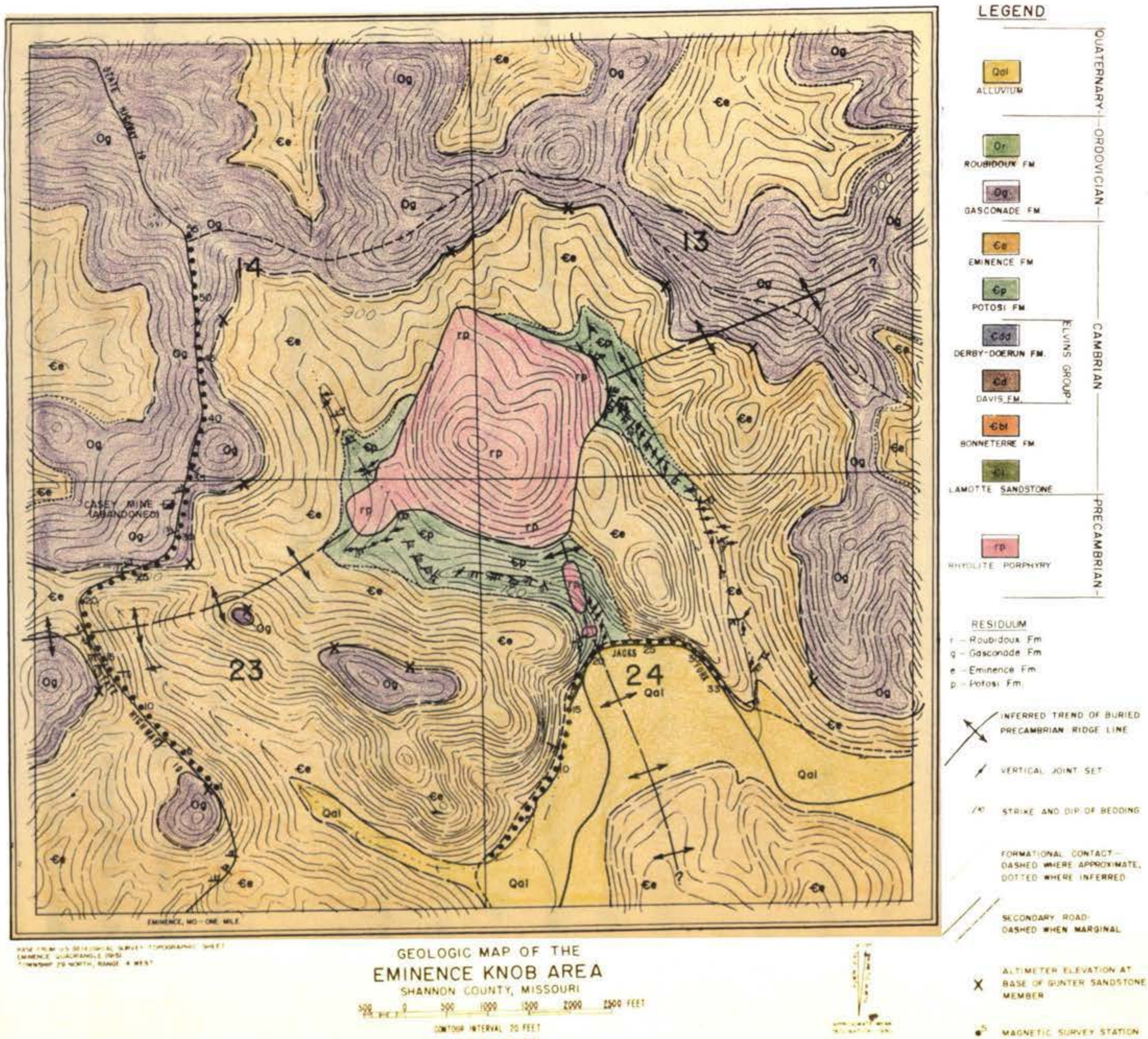
Elevations were taken on the base of the Gunter Sandstone Member with a Paulin altimeter. Locations of these elevations are given on the geologic map (Figure 50), and their apparent relationship to buried Precambrian topography is discussed.

Magnetic traverses were completed at two localities in the area by use of a Jalander flux-gate vertical intensity magnetometer. The locations of magnetic stations of the surveys are shown on the geologic map of the area. The results of these surveys and geologic cross-sections along the lines of the magnetic traverses are given in Figure 54. The relationship of the magnetic anomalies to the inferred trend of buried Precambrian ridge lines is considered.

LOCATION, SIZE, AND ACCESSIBILITY OF THE AREA

The Eminence Knob area lies in the central part of Shannon County, in south-central Missouri. It is rectangular and consists of sections 13, 14, 23, and 24, T. 29 N., R. 4 W., comprising a total area of four square miles.

The area is less than one mile north of Eminence, Missouri.



GEOLOGIC MAP OF THE
EMINENCE KNOB AREA
SHANNON COUNTY, MISSOURI

FIGURE 50

Missouri Highway 19 gives access to the western part of the area. The southern part of the area is accessible by turning eastward from Missouri Highway 19 onto a secondary gravel road immediately north of the highway bridge that crosses Jacks Fork at Eminence. The northern part of the area can be reached by turning eastward from Highway 19 onto a secondary gravel road about two and one-half miles north of Eminence, Missouri. The central part of the area is covered by forest and dense undergrowth, and is accessible only on foot. Secondary roads in the area are in only fair condition, and are difficulty passable during inclement weather.

PREVIOUS WORK

The Eminence Knob area was previously mapped by Bridge (1930) at a scale of 1:62500, in connection with his study of the Eminence and Cardareva quadrangles. Evans (1959) studied a copper prospect known as the Casey Mine, located in the northwest quarter of section 23. He discusses petrology of rhyolite porphyry exposures in the vicinity of Eminence Knob. No other published geologic work is known in the area.

GEOLOGIC SETTING OF THE AREA

The Eminence Knob area lies at the western margin of the Shannon and Carter County region of rhyolite porphyry exposures. In this rugged hilly area, rhyolite porphyry knobs rise to heights of more than 1,300 feet above sea level. The knobs are surrounded by Late Cambrian and Early Ordovician sedimentary rocks that crop out at generally lower elevations along the exposed margins of the knobs.

The Shannon and Carter County region of rhyolite porphyry exposures is separated from the extensive igneous exposures of the St. Francois Mountains by a narrow northwest-trending area of Paleozoic rocks and residuum in Reynolds County. No igneous exposures are known here.

Some characteristics of the region are common with those of the St. Francois Mountains, while others are unique. For this region granite is known only near Van Buren, Missouri. Basic igneous intrusions and other igneous rock types, relatively common in the St. Francois Mountains, are unknown. Exposures of the Roubidoux, Gasconade, and Eminence formations are essentially identical to those observed elsewhere in the Central Ozarks. The Potosi Formation is distinct in that it is almost entirely non-drusy in the Shannon-Carter County area. Although the formation is extensively exposed elsewhere in the Central Ozarks, it rarely crops out in the Shannon-Carter County region. A large number of exposures of the Eminence Formation occur adjacent to Precambrian knobs.

Faults, relatively common in the region of the St. Francois Mountains, are unknown in the Shannon-Carter County region. The thicker sedimentary sequence here suggests that the resurrection of Precambrian topography in the region is at a much earlier stage than elsewhere in the Central Ozarks.

Geomorphology

The greatest elevation in the Eminence area is slightly more than 1,100 feet above sea level. This is along a high ridge in the northwestern part of the area. The flood plain of Jacks Fork is about 600 feet above sea level. The total relief is about 500 feet within 5,000 feet horizontally.

A high ridge extending eastward across the central parts of sections 13 and 14 forms the major drainage divide of the area. Streams to the north of this ridge drain northward into Sutton Creek, which in turn empties into the Current River. South of the ridge, streams empty into Jacks Fork.

Streams adjacent to the Eminence Knob are poorly adjusted to the outline of the knob. At two localities at the western margin of the knob a small stream flows directly upon porphyry, rather than following a course in the probably more easily eroded dolomite around the margins of the knob (Figure 51).

The Eminence Knob area is characterized by high hills and steep slopes. Virtually the only flat land lies adjacent to Jacks Fork. With exception of rhyolite porphyry, rocks of the area respond very similarly to erosion, generally forming steep slopes with very few bluffs. Outcrops are generally scarce, except on very steep slopes, and in stream beds.

A small shut-in formed by stream erosion in rhyolite porphyry occurs near the center of the northwestern quarter of section 24. High, nearly vertical bluffs of dolomite of the Eminence Formation are exposed near the center of section 24, at the bank of Jacks Fork.

STRATIGRAPHY OF EXPOSED FORMATIONS

Four mappable rock units are present in the Eminence Knob area. These include rhyolite porphyry of Precambrian age, and the Potosi, the Eminence, and Gasconade formations. Sedimentary rocks consist predominantly of dolomite, with substantial chert present in the Gasconade Formation. The basal Gunter Sandstone Member of the Gasconade Formation is the only known sandstone unit in the area. The sedimentary rocks are generally

Figure 51. Small shut-in formed where stream flows directly on rhyolite porphyry. The stream has cut its course through igneous rock, rather than following a slightly longer course in dolomite. (NE¼, NE¼, sec. 23, T. 29 N., R. 4 W.)

very thick-bedded and weather to massive almost featureless outcrops.

Rhyolite Porphyry

Eminence Knob is composed entirely of rhyolite porphyry. Megascopically the rock is dark reddish brown to purple, aphanitic, and contains subhedral phenocrysts of pink and grayish white plagioclase feldspar as much as 6 mm. in length; has well developed flow structure with alternating light gray and dark brown bands as much as 6 mm. in width. The long axes of feldspar phenocrysts are generally aligned parallel with the flow banding, and exposures are strongly jointed. These nearly vertical joints trend N. 30°E., N. 75°E., N. 20°W., and N. 75°W.

Evans (1959, pp. 12-28) discusses lithologies of Precambrian rocks cropping out in the vicinity of the Eminence Knob. These appear essentially identical to rhyolite porphyry of Eminence Knob.

Potosi Formation

The Potosi Formation crops out in stream beds along the eastern and western margins of the Eminence Knob. Difficulty was experienced in distinguishing rocks of the Potosi Formation from those of the overlying Eminence Formation. Only the uppermost 100 feet of the formation is exposed in the area. Quartz druse of the Potosi Formation which ordinarily enables the ready separation of the two formations elsewhere in the Central Ozarks, is generally absent in the Shannon and Carter County region. Yet dolomite of the Potosi Formation appears to have a more brownish color and finer crystallinity than do similar units of the Eminence Formation. These features were used to differentiate the formations. Outcrops of the Potosi Formation are recognized only in small areas near Eminence Knob.

An arkosic lens is interlayered in the formation in the bed of a small stream near the center of the southwestern quarter of section 13. This exposure is as follows:

Dolomite, light brown, finely crystalline; contains weathered angular fragments of rhyolite porphyry as much as 4 mm. in diameter; porphyry fragments light brown, in random orientation, deeply weathered....................................1' 0"

All other exposures of sedimentary units adjacent to the Eminence Knob were entirely free of detrital igneous materials.

Eminence Formation

The Eminence Formation crops out in a broad area surrounding the Eminence Knob. Outcrops of the formation are essentially identical to those observed elsewhere in the Central Ozarks. The formation is very thick-bedded, and weathers massive. Bedding planes are rare or absent. The formation is free of arkosic material, even where it crops out immediately adjacent to rhyolite porphyry. The formation is about 200 feet thick in the area. Outcrop areas are characterized by steep slopes with scattered protruding dolomite ledges. Excellent exposures of the formation are located directly south of Eminence Knob, adjacent to Jacks Fork.

Gasconade Formation

The Gasconade Formation is at or near the crests of higher ridges and hills in the Eminence Knob area. The formation is more than 200 feet thick in the area. With exception of the basal Gunter Sandstone Member, it has essentially identical characteristics as in other areas of the Central Ozarks.

The Gunter Sandstone Member of the Gasconade Formation is very well developed in the area, and has a total thickness of about twenty feet. This unit is located at the base of the formation. An excellent exposure of the unit may be seen along the west side of Missouri Highway 19, near the center of the west half of section 23. Although the member is termed a sandstone, in this area it consists largely of argillaceous, cherty dolomite with irregular lenses of sandy dolomite. The uppermost and lower beds of the unit, normally no more than one or two feet thick, are usually pure quartz sandstone.

Quaternary Surficial Deposits

A moderately extensive flood plain is present in the southeastern part of the area, adjacent to Jacks Fork. This alluvial plain consists largely of sand, silt, and clay, with some gravel. Since most tributary streams of the area have high gradients, there is very little alluvial material along their courses. Most streams flow directly upon bedrock.

DEPOSITIONAL ENVIRONMENT OF THE EMINENCE KNOB AREA

Outcrops of the Gasconade and Eminence formations and the limited number of Potosi Formation outcrops within a narrow zone next to the knob were examined for indications of environments of deposition. Particularly sought were mud cracks, ripple marks, and cross-bedding.

As noted, detrital igneous material was observed at one locality in the Potosi Formation immediately adjacent to rhyolite porphyry at the eastern margin of the knob. At many other localities in the area, dolomite crops out directly adjacent to rhyolite porphyry exposures. The dolomites are entirely free of detrital igneous material. None shows direct evidence of shallow water conditions.

The lack of evidence for shallow water or high energy environment suggests that the crest of Eminence Knob may have been submerged below wave base during essentially all of Late Potosi, Eminence, and Early Gasconade time. Shallow water conditions probably existed during deposition of the arkosic material at the east margin of the knob.

The lack of distinctive sedimentary features (mud cracks, ripple marks, etc.) and the general uniformity of sedimentary rocks with those seen elsewhere in the Central Ozarks suggests the Eminence Knob had little influence upon depositional environments of surrounding sediments during Late Potosi, Eminence, and Early Gasconade time.

STRUCTURE OF THE AREA

Peripheral dips, joints, and elevations on the base of the Gunter Sandstone Member were mapped in the Eminence Knob area. No fault or slump structures were observed. Results of measurement of peripheral dips at the eastern flank of the knob are shown in Figure 52. Joints in a stream bed at the eastern flank of the knob are analyzed by use of overlapping strike diagrams (Figure 53). The relationship of elevations on the base of the Gunter Sandstone Member to apparent configuration of Precambrian topography is discussed.

Peripheral Dips

Dips as high as 34 degrees exist in sedimentary rocks at the flanks of Eminence Knob. These rocks, almost without exception, strike parallel to the flanks of the knob, and dip away from the knob.

Detailed dip measurements were taken in a stream bed that flows generally southeastward away from the eastern flank of Eminence Knob. The results of these measurements were plotted on graph paper opposite distance in order to demonstrate rate of decrease in dip with increasing distance from the flanks of the knob. Figure 52 shows the results of these measurements.

The decrease in dip along the stream bed is rapid, and essentially linear for a distance of about 135 feet from the knob. Within this 135 foot interval, the dip decreases to about half its maximum value. In the interval from 135 feet to about 300 feet, dip continues to decrease, but at a slower rate. From 300 feet to about 700 feet, decrease in dip is very slow. Beyond 700 feet very little decrease in dip is noted.

Dips as great as 17 degrees occur in exposures along Missouri Highway 19, in the southwestern part of the area. These dips indicate the presence of an anticlinal structure with its axis in the northwestern quarter of section 23.

Joint Patterns

Numerous joints were noted in the beds of small streams that flow on either side of Eminence Knob. Very few joints were seen elsewhere, largely due to poor exposures. All joints observed are vertical.

Joints in the stream bed at the eastern margin of Eminence Knob were analyzed by use of overlapping strike diagrams, shown in Figure 53. This figure shows the surface topographic contours of the rhyolite porphyry of Eminence Knob, the generally southward flowing stream at its eastern margin, and the position of individual joint sets in the stream. Each joint set represents two vertical joints. The strike diagrams used in this illustration are arranged in a manner similar to those presented in earlier

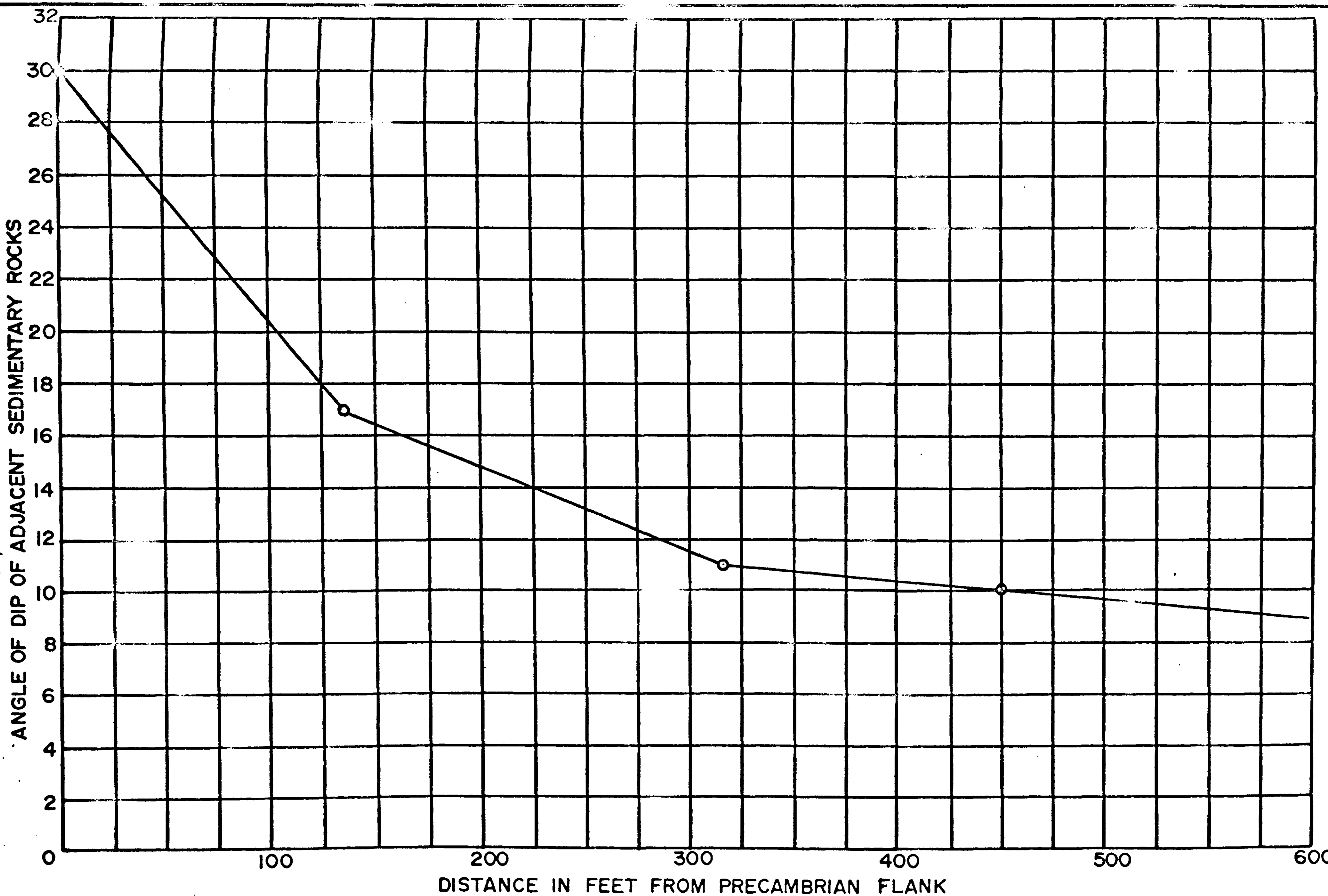


FIGURE 52. DECREASE IN ANGLE OF DIP WITH INCREASING DISTANCE FROM EXPOSED PRECAMBRIAN FLANK—EAST FLANK EMINENCE KNOB

chapters.

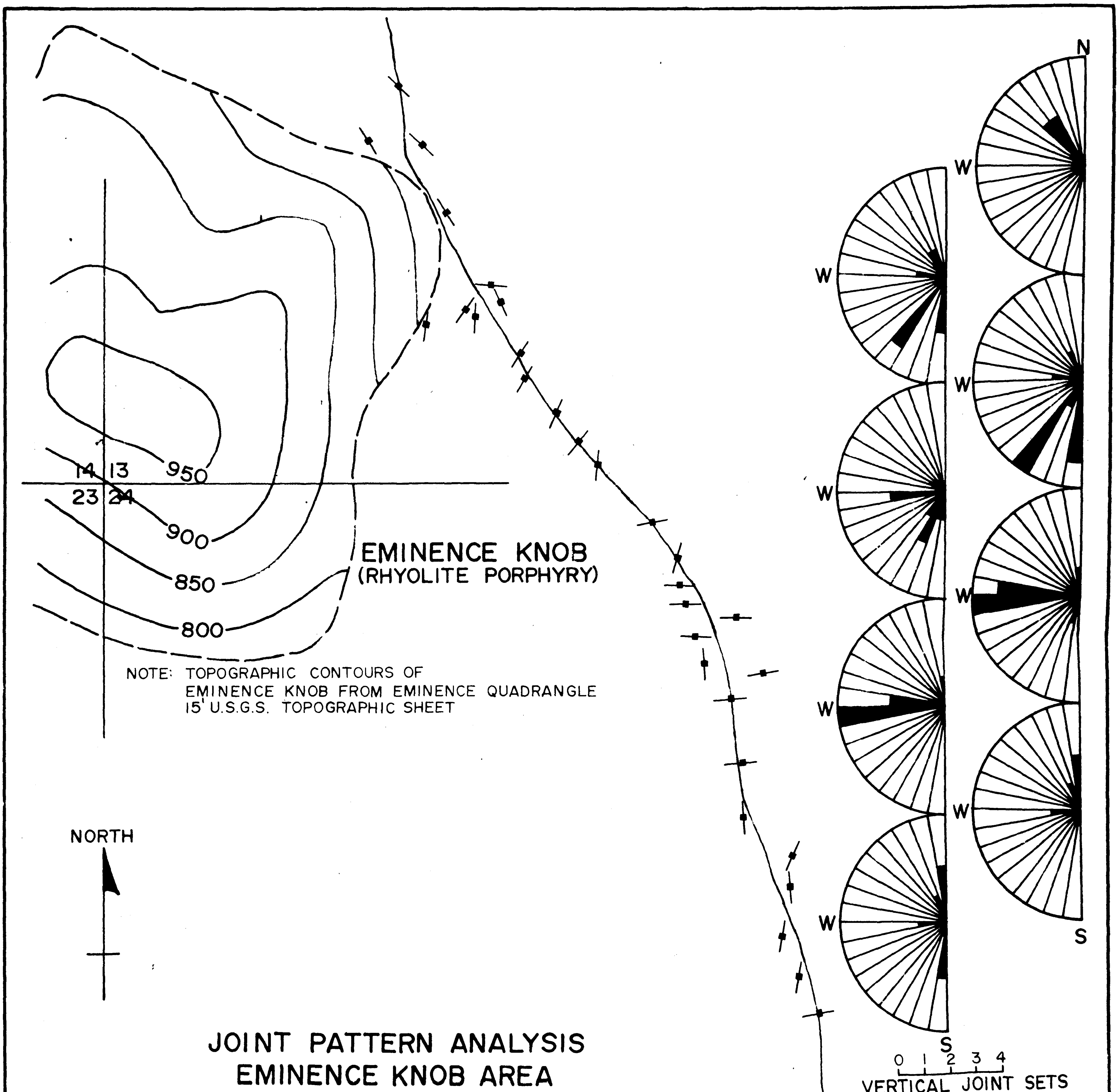
The southernmost two strike diagrams of Figure 53 indicate most joints in this interval of the stream strike generally northward, with a few striking westward. The third and fourth diagrams from the south, northward, show an abundance of joints in this interval, and a very strong westward component of strike. A few joints in these intervals strike northward. The joints included in the four southernmost diagrams are relatively far removed from Eminence Knob, and their strikes seem little influenced by the configuration of the knob.

The fifth and sixth strike diagrams from the south show significant deviation from the generally northward and westward strikes shown in the lower diagrams. They indicate a strong southwest component of strike, approximately parallel to the eastern flank of Eminence Knob.

The uppermost two strike diagrams show strikes generally to the northwest and southwest, and appear to reflect the relatively sharp nose at this margin of Eminence Knob. Results of joint measurements on the south and west of Eminence Knob reflect similar relationship to the knob boundary as those shown by measurements east of the knob. With few exceptions the joints strike generally parallel to the flanks of the knob.

Altimeter Elevations of the Gunter Sandstone Member

The locations of elevations taken on the base of the Gunter Sandstone Member of the Gasconade Formation are shown in Figure 50. Bridge (1930, p. 164) completed a generalized structure map drawn on the top of the Gunter Sandstone Member in the Eminence and Cardareva quadrangles, and suggests that it indicates the approximate configuration of the underlying Precambrian surface. The present, more detailed study, was



JOINT PATTERN ANALYSIS
EMINENCE KNOB AREA
SCALE: 1" = 500'
ELEVATION OF CREEK BED APPROXIMATELY
650 FEET ABOVE SEA LEVEL

FIGURE 53

undertaken to substantiate or modify his general conclusions.

The highest elevation on the Gunter Sandstone Member was measured just north of the center of section 23. Here, a small exposure of the sandstone occurs near the crest of a hill at 975 feet above sea level. This outcrop lies almost exactly in line with a rhyolite porphyry ridge extending southwestward from Eminence Knob, and near the crest of an anticlinal structure indicated by dips taken along Missouri Highway 19.

The lowest elevation on the Gunter Sandstone Member was 700 feet above sea level, measured near the center of the east half of section 24, in an area of moderately strong southeast dip. The presence of a relatively deep sedimentary basin in this direction is suggested.

Elevations on the base of the Gunter Sandstone Member are somewhat above 900 feet throughout most of the western half of the area. Along the northern margin of Eminence Knob, elevations drop to less than 900 feet above sea level, and again rise to more than 900 feet above sea level near the center of the southern half of section 13. These variations are relatively small, and suggest that no prominent Precambrian ridge extends northward from Eminence Knob. The slight rise in elevation of the Gunter Sandstone Member northeast of the knob suggests the possibility of a less pronounced ridge in this direction.

From the evidence presented, elevation control on the base of the Gunter Sandstone Member can be very useful in determining the trend of buried Precambrian topography even in large scale mapping. The practical problem of locating the member in the field is the main difficulty in using this method. Other key beds, if present, would prove as useful.

Inferred Trends of Buried Precambrian Ridges

Buried Precambrian ridge lines are suggested southwest, south, and northeast from Eminence Knob, as shown in Figure 50. A prominence of rhyolite porphyry outcrop at the southwest margin of the knob marks the beginning of one buried ridge. From here, rhyolite porphyry extends 1,000 feet southwestward from local margins of the knob, and disappears under sedimentary rocks of the Eminence Formation.

The base of the Gunter Sandstone Member stands at 975 feet just north of the center of section 23, and is the highest known elevation of this unit in the Eminence Knob area. This outcrop of the Gunter Sandstone Member lies almost directly above the inferred location of the buried Precambrian ridge.

Dips of sedimentary units measured along Missouri Highway 19 in the northwestern quarter of section 23 indicate an anticlinal structure that coincides with the inferred trend of the buried ridge. Rocks north of the inferred ridge dip at 8 degrees to 13 degrees northward. At the crest of the ridge, the dip is about 5 degrees toward the southwest, suggesting the buried ridge is sloping toward the southwest. South of the inferred ridge, sedimentary rocks dip at about 16 degrees toward the south.

After these geologic features were recognized, a vertical intensity magnetic traverse was completed along Missouri Highway 19, and across the axis of the ridge. The magnetic stations are shown on Figure 50. The magnetic profile and a geologic cross-section along the line of the magnetic traverse are shown in the upper part of Figure 54. The geologic cross-section is based upon surface outcrops and the inferred trend of the buried Precambrian ridge.

As seen in Figure 54, the magnetic profile also suggests the presence of a buried Precambrian ridge. The results of this survey are discussed in more detail in a later section.

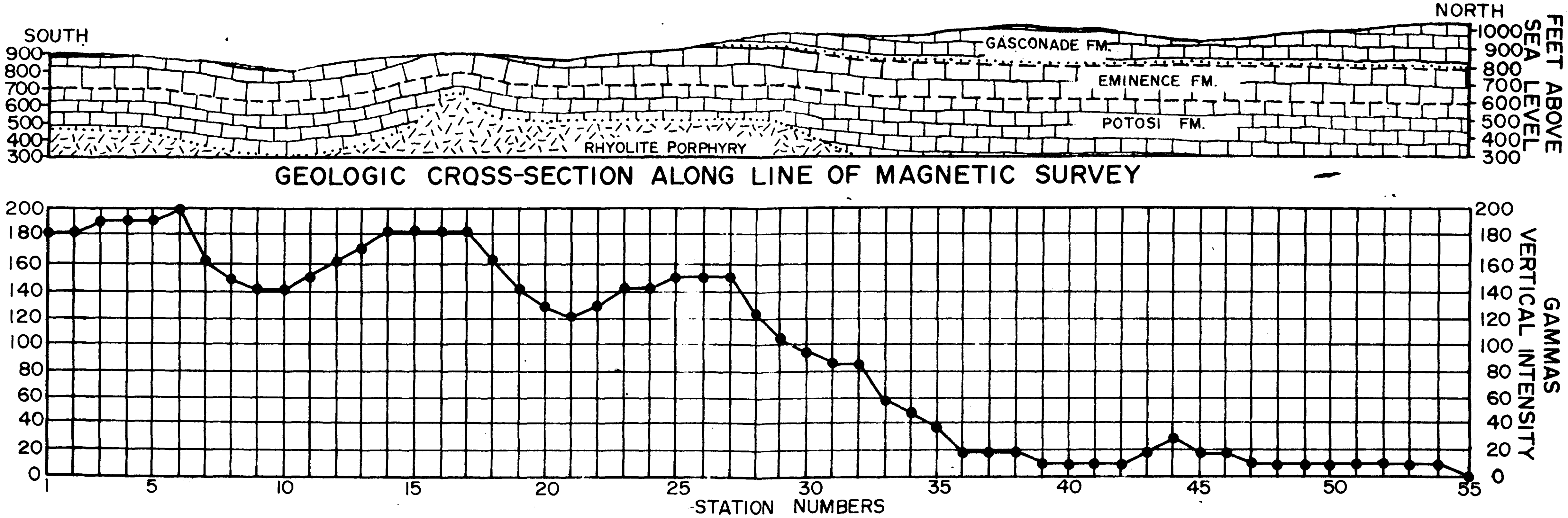
An inferred buried Precambrian ridge which extends generally southward from the south margin of Eminence Knob is suggested by a very narrow rhyolite porphyry ridge exposed directly south of the knob, a small porphyry exposure south of the ridge, results of a magnetic traverse across the ridge, and a sharp deflection in the course of Jacks Fork south of Eminence Knob.

The southern-most small exposure of rhyolite porphyry (Figure 50) is 1,250 feet south of the southern flank of Eminence Knob. It lies directly in line with the larger ridge to the north. Figure 55 shows a portion of this narrow elongated rhyolite porphyry ridge south of Eminence Knob. The igneous rock of flanks of this narrow ridge, where exposed, slope at about 70 degrees.

Results of a magnetic traverse along a secondary road across the suggested trend of the buried portion of the ridge are shown in the lower part of Figure 54. The magnetic data show correspondence with the crest of the inferred Precambrian ridge.

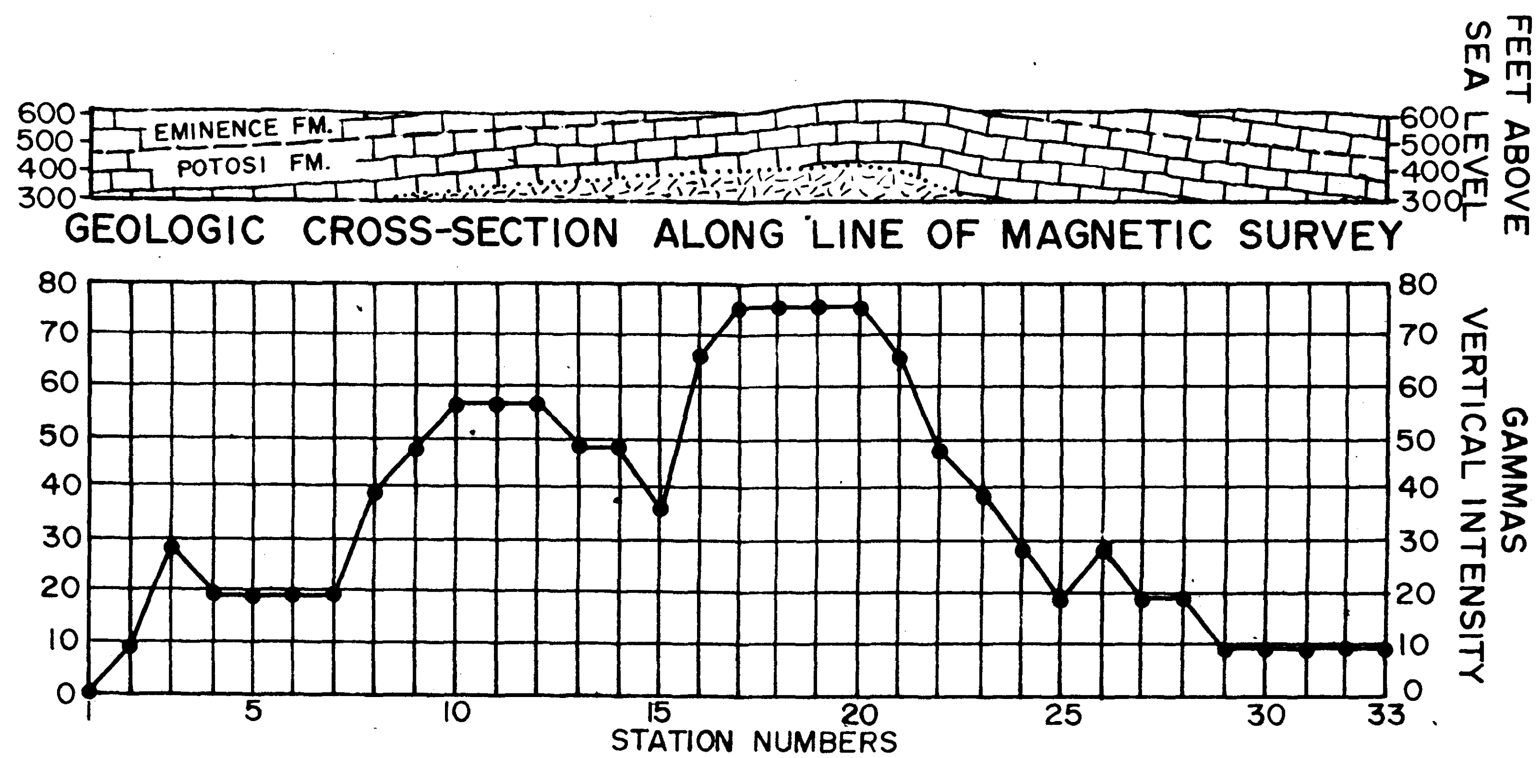
Although any Precambrian exposures present in the flood plain of Jacks Fork are covered by alluvium, it is very likely that the river cut rhyolite porphyry of the buried Precambrian ridge. The river appears to have been deflected generally northwestward along the margin of the ridge to the point where it now crosses.

The higher than normal elevations on the base of the Gunter Sandstone Member at slightly higher than 900 feet above sea level suggest



MAGNETIC SURVEY ALONG MISSOURI HIGHWAY 19, WEST OF EMINENCE KNOB

NOTE: GEOLOGIC CROSS-SECTION BASED UPON SURFACE OUTCROP DATA AND INFERRED TREND OF BURIED PRECAMBRIAN RIDGES, DETERMINED THROUGH DETAILED MAPPING OF PRECAMBRIAN EXPOSURES. SURFACE TOPOGRAPHY FROM U.S.G.S. TOPOGRAPHIC MAP. NO VERTICAL EXAGGERATION. SCALE: 1" = 750'



MAGNETIC SURVEY ALONG SECONDARY ROAD, SOUTH OF EMINENCE KNOB

SEE FIGURE 50, GEOLOGIC MAP OF THE EMINENCE KNOB AREA FOR LOCATION OF INDIVIDUAL STATIONS. STATION SPACING 150 FEET. SURVEY COMPLETED MAY, 1963. JALANDER MAGNETOMETER 57126, CALIBRATED SCALE VALUE 9.5 GAMMAS PER SCALE DIVISION. SURVEY ACCURACY ±5 GAMMAS.

FIGURE 54

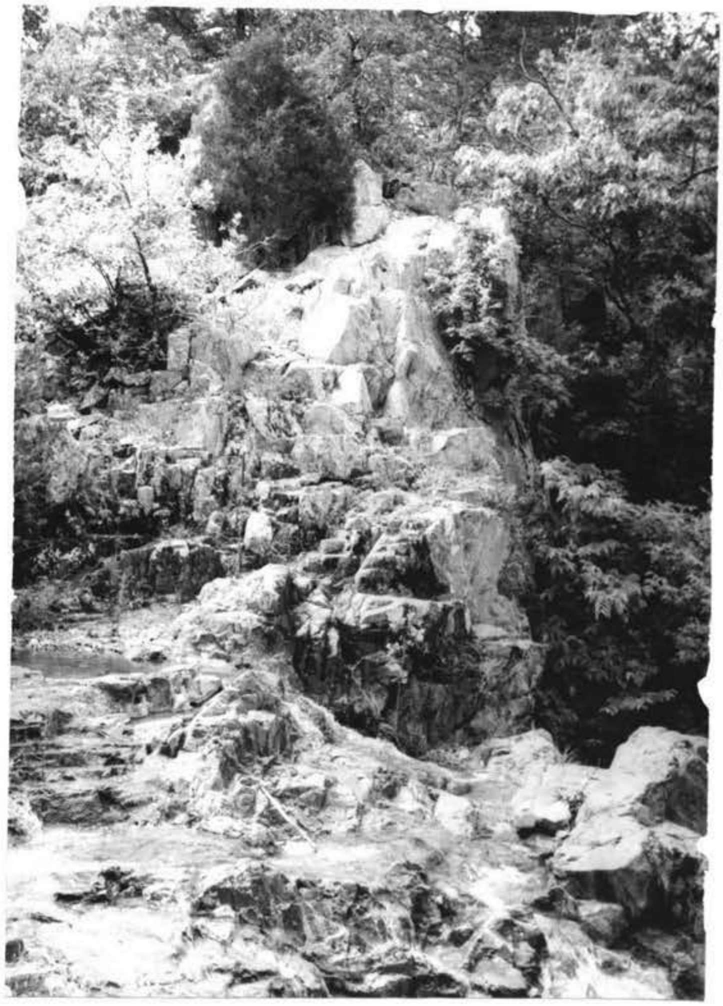


Figure 55. A narrow rhyolite porphyry ridge with exposed steep flanks that extends southward from Eminence Knob. A smaller isolated porphyry exposure lies about 250 feet south of this ridge. These exposures lie along the crest of an inferred buried ridge that extends southward from Eminence Knob. The numerous nearly vertical joints of this exposure strike N. 30°E., N. 75°E., N. 20°W., and N. 75°W.

the northeastward continuation of the Precambrian ridge from the eastern margin of the Eminence Knob.

MAGNETIC CHARACTERISTICS OF THE AREA

No aeromagnetic coverage of the area is available at present (1966). The total magnetic field strength at Eminence Knob is about 56,600 gammas, or 0.566 gauss. The inclination of the total field is about 68°10' (U. S. Coast and Geodetic Survey, 1955).

As noted, two vertical intensity magnetic traverses were completed in the Eminence Knob area and the results are presented in Figure 54. A maximum magnetic relief of 200 gammas was obtained in the traverse along Missouri Highway 19. The magnetic profiles show a close correspondence to general configuration of the underlying Precambrian topography.

The first of the traverses, along Missouri Highway 19, included fifty-five stations, spaced at 150 feet apart. The total length of the traverse is 8,100 feet and station fifty-five, at the north end of the traverse, was used as base station.

For the interested reader the following data may be import. From the north southward, vertical intensity readings remain within 20 gammas of the initial base station reading until station 36 is reached. At station 36 north sedimentary rock dips are present in outcrops at the side of the highway. Here, vertical magnetic intensity shows a corresponding increase. From station 36 to station 27, an increase of 120 gammas is measured on the traverse. From station 27 to station 21, where the highway turns southwest and parallels the strike of the inferred buried ridge, magnetic intensity decreases by about 30 gammas. Here, the buried ridge may be sloping slightly toward the southwest. This could account for the slight decrease in magnetic response.

At station 21, where the survey once again begins to approach the geologically inferred crest of the buried ridge, magnetic response likewise shows an increase. At station 17, the presumed buried crest, the profile shows 180 gammas. This remains constant until station 14.

From station 14 southward magnetic readings gradually decline. They reach a minimum at station 10 which coincides with a structural syncline as indicated by dips of sedimentary rocks along Highway 19.

At station 9 the magnetic response rapidly increases, reaching a maximum for the traverse of 200 gammas at station 7. From station 7 to station 1, the magnetic response remains at or near its maximum for the survey. The higher magnetic readings from station 9 to station 1 probably reflect a gradual rise in the Precambrian surface toward the south. This accords with dips of sedimentary units in the interval from station 7 to station 1. Another factor may be a gradual increase in the magnetic susceptibility of Precambrian rocks in this direction.

A second magnetic traverse, totalling thirty three stations and 4,800 feet in length was completed near the south margin of Eminence Knob. The traverse started at the west line of section 24, near the southern boundary of the area. Station 1 was used as a base station for the traverse.

A gradual, but somewhat irregular increase in magnetic response is noted from station 1 to station 17. At stations 17 through 20, where maximum readings for the survey are obtained, the vertical magnetic response is about 75 gammas higher than at station 1. Station 20 lies almost directly over the inferred crest of the buried Precambrian ridge. From station 20 to station 25 vertical magnetic response decreases by more than 55 gammas. This suggests the crest of the buried ridge has been passed. From station 25 to station 33, magnetic intensity continues to decrease, but at a much slower rate.

The magnetic relief in the Eminence Knob area suggests a magnetic susceptibility higher than the granite of Czar Knob (1.147×10^{-3}) and lower than the trachyte porphyry of Little Pilot Knob ($5,250 \times 10^{-3}$). These data suggest that aeromagnetic coverage and additional ground magnetic surveys would be useful in interpreting buried Precambrian topography in the region of Eminence Knob.

SUMMARY AND CONCLUSIONS

Eminence Knob is in the Shannon and Carter County region of rhyolite porphyry exposures. This region is separated from igneous exposures of the St. Francois Mountains by an area in Reynolds County where no igneous exposures are known. The Shannon-Carter County region differs from other areas of the Central Ozarks in the predominance of rhyolite porphyry, the absence of mappable faults, the lack of typical quartz druse in the Potosi Formation, and the almost complete absence of exposures of sedimentary rocks older than the Potosi Formation.

The poor adjustment of streams to the configuration of Eminence Knob, and the fact that nearby hills underlain by dolomite stand at higher elevations than does the probably more resistant rhyolite porphyry of Eminence Knob suggest the rhyolite porphyry of Eminence Knob has been exposed in relatively recent geologic time.

Eminence Knob is composed of strongly flow-banded, reddish brown to purple rhyolite porphyry. The rock is highly jointed, and contains plagioclase feldspar phenocrysts as much as 6 mm. long.

Sedimentary rocks of the area are generally similar to those observed elsewhere in the Central Ozarks. The Potosi Formation, however, is non-drusy and can be distinguished from the overlying Eminence Formation only by a more brownish color and a finer crystallinity. With exception of a thin arkosic zone at one locality, no evidences of shallow water conditions were noted in the Eminence Knob area.

The almost complete lack of evidence for shallow water conditions adjacent to Eminence Knob suggests the crest of the knob was submerged below wave base during most of Late Potosi, Eminence, and Early Gasconade time. The Eminence Knob may have had a little influence upon depositional environments that existed in its vicinity during this time.

No faults or slump structures are recognized in the Eminence Knob area. Peripheral dips measured at a large number of localities adjacent to the knob are as high as 34 degrees. At the east flank of the knob these dips are analyzed graphically (Figure 52). This graph indicates a rapid and essentially linear decrease in rate of dip for a distance of about 100 feet from the knob, a continued but slower decrease for the next 200 feet, and a very slow decrease in the interval from 300 to 700 feet. Dips measured along Missouri Highway 19 indicate an anticlinal structure in the northwestern quarter of section 23.

Joint sets in a stream bed at the east margin of the knob were analyzed by use of overlapping strike diagrams (Figure 53). These diagrams show a general northward and eastward strike for joints that are located some distance away from the knob. As the knob is approached, the joints show strikes either parallel or tangential to the flanks of the knob. Other joints in the Eminence Knob area, while not analyzed graphically, show this same parallel or tangential relationship.

Elevations on the base of the Gunter Sandstone Member of the Gasconade Formation taken at thirteen locations in the quadrangle range from 700 feet to 975 feet, or a structural relief of at least 275 feet. These significant variations suggest the presence of two buried Precambrian ridges, and a sedimentary basin in the vicinity of the Eminence Knob. Structural mapping of the Gunter Sandstone Member or other key beds should prove useful in determining the trend of buried Precambrian topography, even in large scale mapping.

Buried Precambrian ridges are postulated southwest, south, and northeast from Eminence Knob. The presence of these buried ridges is indicated by the configuration of the exposed rhyolite porphyry, dips of sedimentary rocks in the area, results of elevations of the Gunter Sandstone Member, two magnetic profiles in the area, and in one instance by a sharp deflection in the course of Jacks Fork.

No aeromagnetic coverage of the Eminence Knob area is available (1966). Two magnetic traverses completed in the area show a close correspondence of magnetic response to buried Precambrian ridge lines, as indicated by geologic data. The magnitude of the magnetic response suggests the rhyolite porphyry of the Eminence Knob area has a magnetic susceptibility higher than the granite of Czar Knob, and lower than the trachyte porphyry of Little Pilot Knob.

THE CALEDONIA AREA

INTRODUCTION

The Caledonia area is near the northern perimeter of major igneous exposures of the St. Francois Mountains. The Palmer Fault Zone (Figure 57) lies at the northern boundary of the area. This fault has a displacement of more than 800 feet and is downthrown to the north.

A resurrected ridge of Precambrian rhyolite porphyry, nearly three miles long, extends in a northeasterly direction in the western portion of the area. Three other much smaller igneous exposures also crop out.

This area affords an opportunity to observe outcrops of the Bonneterre Formation and the Lamotte Formation at the margins of Precambrian exposures. Neither of these formations crops out in previously discussed areas. Detailed mapping of the igneous exposures and the immediate area makes possible a comparison of these exposures with the associated magnetic anomalies obtained in an aeromagnetic survey of the area. The area is also especially suitable for study because the ages and distribution of sedimentary and igneous rocks seem generally typical for this part of the Central Ozarks.

LOCATION, SIZE AND ACCESSIBILITY OF THE AREA

The Caledonia area is near the southern boundary of Washington County, Missouri (Figure 57). The area is rectangular and is about three miles wide and two and one-half miles long. Slightly more than seven square miles is represented. The city of Caledonia is in the extreme southeastern portion. Missouri State Highway 21 crosses the area in a northerly direction, while Missouri State Highway C crosses it in an easterly direction, to intersect State Highway 21 about one mile north of Caledonia. The highways, as well as secondary roads in the area, are well maintained and in generally good condition.

PREVIOUS WORK

The Caledonia area was previously mapped by C. L. Dake (1930) at a scale of 1:62500. No other work has been published on the area.

GEOLOGIC SETTING OF THE AREA

A distinctive geologic feature of the Caledonia area is an elongate rhyolite porphyry ridge in the western part that extends northeastward for nearly three miles. The Bonneterre Formation borders all margins of this ridge and crops out at the surface throughout much of the area. The Lamotte Formation crops out at seven known localities within the area. Rhyolite porphyry is also present at three of these localities and may be near the surface at a fourth locality.

Joint fractures are common but generally not abundant in the sedimentary rocks of the Caledonia area. Most of these were observed in the beds of small streams.

Dips as high as 12 degrees occur in the area. The higher dips lie near igneous exposures.

Although the Palmer Fault Zone lies immediately to the north, no faults are recognized in the Caledonia area.

Geomorphology

The Caledonia area has moderate relief, with the greatest elevation

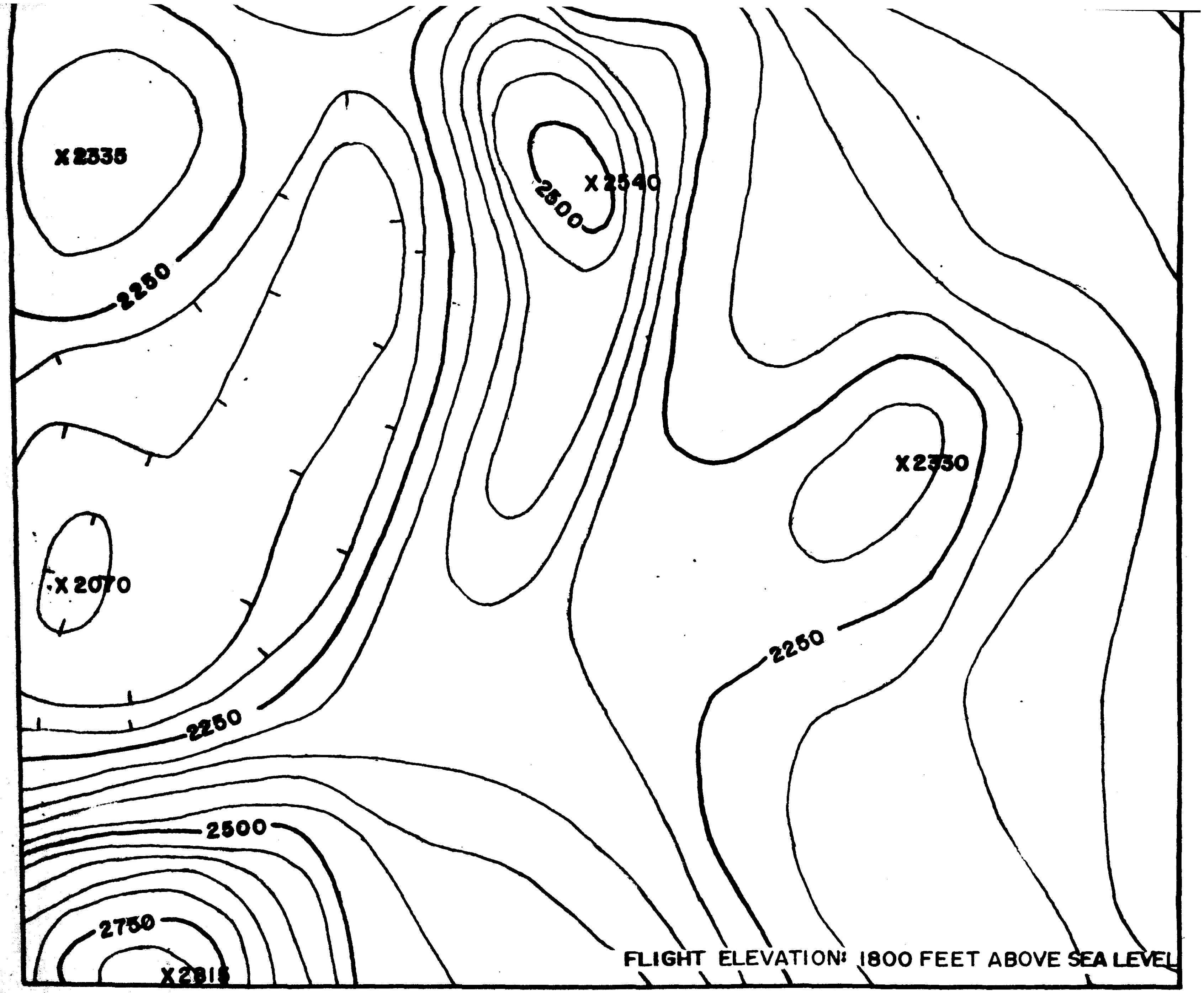


FIGURE 56

TOTAL INTENSITY AEROMAGNETIC MAP OF THE CALEDONIA AREA

CONTOUR INTERVAL 50 GAMMAS

FROM TOTAL INTENSITY AEROMAGNETIC MAP OF POTOSI QUADRANGLE, MISSOURI, U.S.G.S. MAP 13, 1950

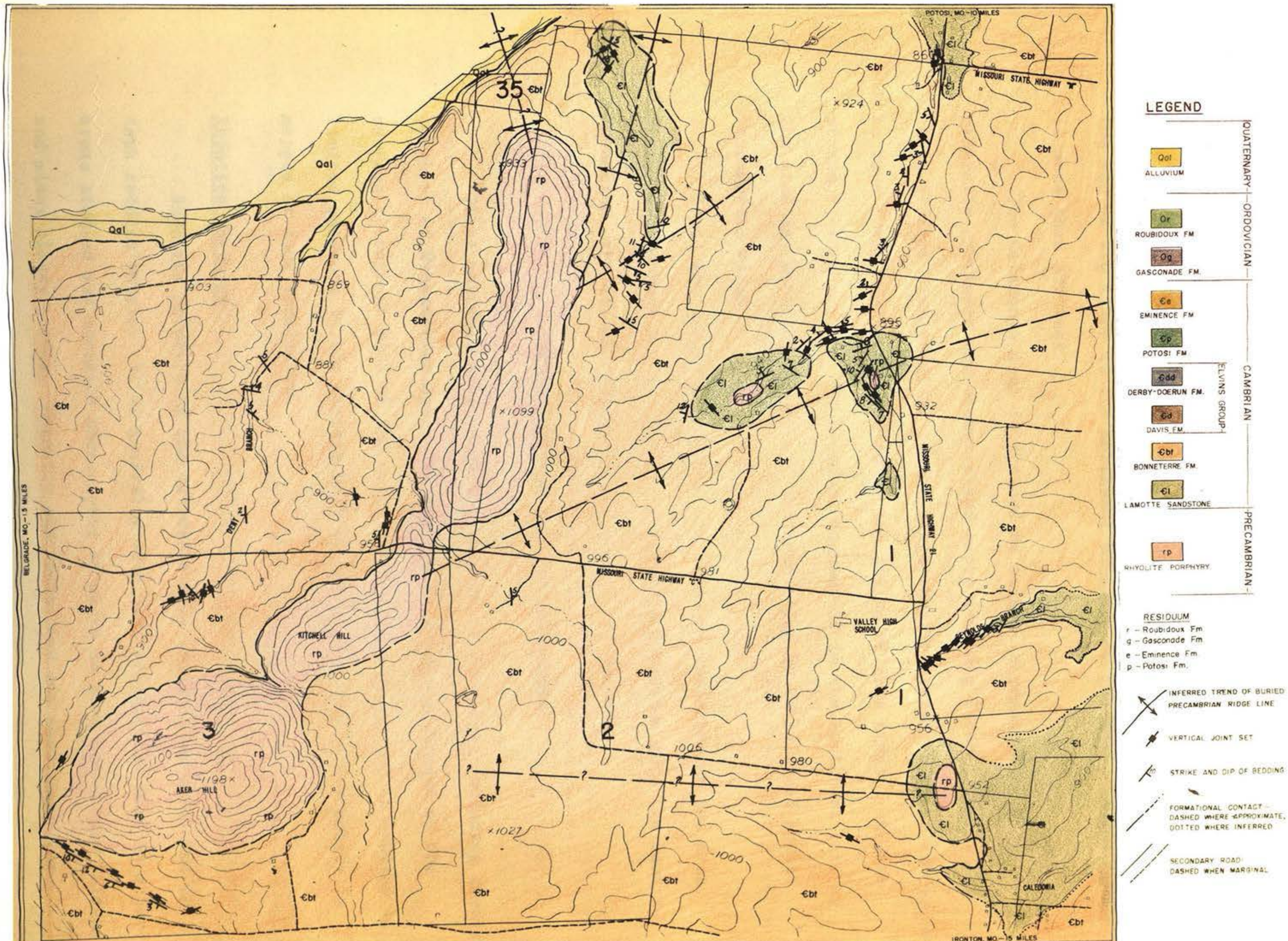


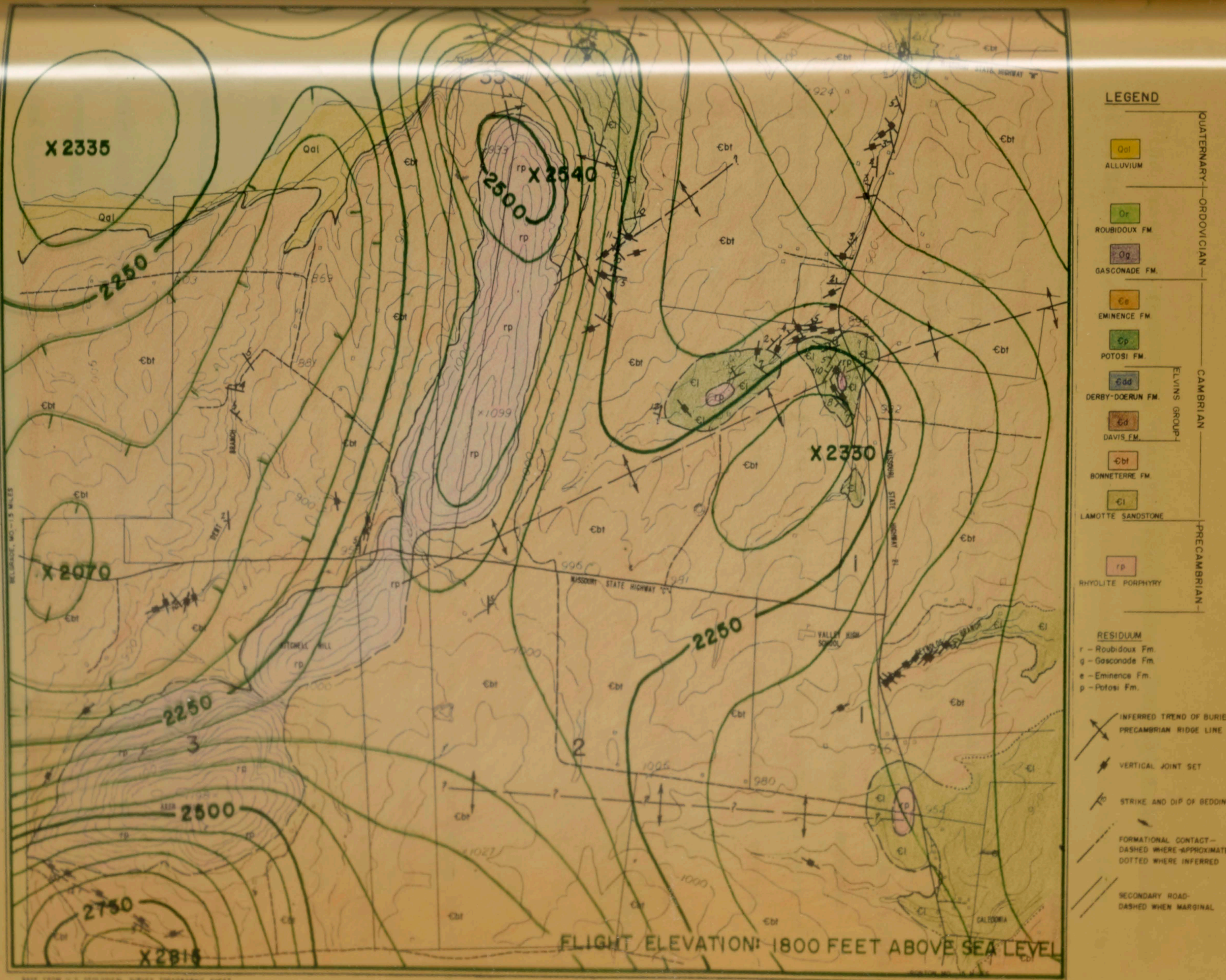
FIGURE 57

GEOLOGIC MAP OF THE
CALEDONIA AREA
WASHINGTON COUNTY, MISSOURI

500 0 500 1000 1500 2000 2500 FEET

CONTOUR INTERVAL 20 FEET

FIGURE 56



TOTAL INTENSITY AEROMAGNETIC MAP OF THE CALEDONIA AREA

CONTOUR INTERVAL 50 GAMMAS

FROM TOTAL INTENSITY AEROMAGNETIC MAP OF POTOSI QUADRANGLE, MISSOURI, U.S.G.S. MAP 13, 1950 at the crest of Aker Hill, near the southwestern corner of the quadrangle at 1,198 feet, and the lowest elevation, somewhat less than 840 feet, in the bed of Big River at the northwest boundary of the area. Total relief is more than 350 feet.

The Caledonia area is drained by several streams which flow generally northward and eastward and empty into Big River. Two of the large streams flow parallel to the large rhyolite porphyry ridge and appear to have their course controlled by the strike of this ridge. Another stream flowing parallel to Missouri Highway 21 in the northeast part of the area may have its course in part controlled by an inferred buried Precambrian ridge.

Broad low ridges and open stream valleys characterize the area. Where streams have cut through the Bonneterre Formation into the Lamotte Formation, the stream valleys become deeper and narrower.

STRATIGRAPHY OF EXPOSED FORMATIONS

Three mappable rock units are exposed in the area, including rhyolite porphyry of Precambrian age. The Bonneterre Formation occurs at the surface throughout much of the area. The Lamotte Formation is exposed in limited outcrops in the eastern half of the area. Rhyolite porphyry is mapped at four localities.

Rhyolite Porphyry

Rhyolite porphyry of the Caledonia area ranges from brick red to dark reddish purple. It is generally much less porphyritic than in other areas studied and contains phenocrysts of white to pink orthoclase feldspar and minor glassy quartz. Magnetic susceptibility was determined for rhyolite porphyry samples from a highway cut on Missouri Highway C where it crosses the large northeastward trending rhyolite porphyry ridge.

Bonneterre Formation

Only the lower 100 feet of the Bonneterre Formation is in the Caledonia area. The unit is particularly thin in the eastern half where the Lamotte Formation crops out. The Bonneterre Formation consists of fairly pure, fine to coarsely crystalline dolomite. Individual crystals have a light gray, milky, almost translucent appearance. The formation is generally medium to thick-bedded. Thin-bedded and shaly facies crop out at a few localities in the Caledonia area (Figure 58). A basal sandy facies of the formation occurs at several localities.

A distinctive conglomerate zone is in the Bonneterre Formation in the bed of Dent Branch about 350 feet north of the point where it flows under Missouri State Highway C (Figure 58). The groundmass of this conglomerate consists of medium to coarse-grained, arkosic and partly dolomitic sandstone. Pebbles and cobbles consist of light gray, coarsely crystalline limestone and strongly bleached rhyolite porphyry. The conglomerate is generally poorly sorted and most cobbles and pebbles are only partly rounded.

The coarse fragments of this conglomerate suggest a depositional environment of considerable energy, while the angularity of most fragments indicates relatively short transport. Field relations show this conglomerate lies in the transition zone between the Bonneterre Formation and the Lamotte Formation with a probable easterly source.

Lamotte Formation

The Lamotte Formation, consisting of only the uppermost fifty feet, crops out at seven general localities in the eastern half of the area. This interval consists largely of reddish brown, generally thin-bedded, arkosic sandstone. It is dolomitic near the transition zone with the Bonneterre Formation. A typical exposure of the formation in the Caledonia area is shown in Figure 6. The Lamotte Formation is deeply weathered and very friable in outcrops along Missouri State Highway 19 about one mile north of Valley High School (Figure 60). About 500 feet west of these outcrops, the sandstone is well-cemented and compact. At a few outcrops in the Caledonia area, the sandstone is medium-bedded, well-sorted, and nearly free of arkosic material.

Lamotte Formation - Bonneterre Formation Contact

The Lamotte Formation - Bonneterre Formation contact is well exposed in the eastern half of the Caledonia area. This contact is entirely transitional and conformable. The sandstone grades upward into a more shaly dolomitic phase which is locally conglomeratic, and finally into beds of nearly pure dolomite. The transitional nature is most readily observed in Reynolds Branch, about 2,000 feet east of Valley High School. Here, both the Bonneterre Formation and the Lamotte Formation are strongly jointed by northeast and northwest sets.

DEPOSITIONAL ENVIRONMENT OF THE CALEDONIA AREA

Arkosic sandstone or nearly pure quartz sandstone in the Lamotte Formation, limestone and rhyolite porphyry conglomerate, and nearly pure crystalline dolomite of the Bonneterre Formation suggest the sedimentary

Figure 58. Bonneterre Formation near transition with Lamotte Formation on northwest side of Aker Hill. Outcrop consists largely of thin-bedded to laminar, finely crystalline arkosic dolomite. Beds dip northwest about 5 degrees.

Figure 59. Conglomerate within basal part of Bonneterre Formation, in stream bed 1,500 feet northwest of Kitchell Hill. Dark groundmass is medium to coarse-grained arkosic and ferruginous dolomite. Cobbles and pebbles are light gray, coarsely crystalline limestone and strongly bleached rhyolite porphyry. Large cobble near rock hammer is bleached rhyolite porphyry.

Figure 60. Lamotte Formation outcrop immediately east of Missouri Highway 21, about 3,700 feet north of Valley High School, and 500 feet north of a rhyolite porphyry exposure. The sandstone units are deeply weathered, friable, and dip 7 degrees toward the north.

environments in the area.

The arkosic material and cross-bedding of the Lamotte Formation clearly suggest a shallow marine clastic environment. The arkosic and conglomeratic content in outcrops increase near rhyolite porphyry exposures. This suggests much of the arkosic material is locally derived, probably in part by wave action upon the exposed rhyolite porphyry ridges.

The transitional nature of the contact between the Lamotte Formation and the Bonneterre Formation suggests a gradual development of a deeper marine environment. This change was slow and may have been partly interrupted by brief recurrences of shallow water conditions. This is indicated by the coarse limestone and rhyolite porphyry conglomerate described earlier. The nearly pure dolomite facies of the Bonneterre Formation indicates a deeper marine carbonate environment. Since the dolomite is largely free of arkosic material, it is likely that the rhyolite porphyry ridges were submerged below wave base during its deposition.

STRUCTURE OF THE AREA

Sedimentary rocks of the Caledonia area are generally nearly flat-lying. Where these strata approach buried or resurrected Precambrian hills, they show increases to a maximum of 12 degrees dip. No faults are recognized.

More than fifty vertical joints were mapped in the Caledonia area, mostly along stream beds. The strike of some joints appears to be related to the outlines of Precambrian exposures, but in others no clear relationship was recognized.

Peripheral Dips

Strata dips to 12 degrees occur along the southern margin of Aker Hill. Here thick-bedded units of the Bonneterre Formation dip southward from the hill and strike generally parallel to its exposed flanks.

Two small igneous exposures are mapped in an area about one mile north of Valley High School, and immediately west of Missouri Highway 21. Immediately adjacent to rhyolite porphyry, the maximum dip is only 12 degrees. Outcrops of both the Bonneterre Formation and Lamotte Formation display relatively low dips. Figure 61 shows an outcrop of the Lamotte Formation less than 400 feet from the exposed rhyolite porphyry west of Missouri Highway 21.

Unusually steep dips in strata occur near the eastern margin of the larger rhyolite porphyry ridge and just south of its northern tip, slightly more than one mile northwest of Valley High School. From the south, shaly dolomite is encountered with dips about 10 degrees south. Within a 200 foot interval in the stream, the dip changes to westward about 11 degrees, and then about 200 feet further north the dip is about 10 degrees northward. Although no igneous exposures were observed, these steep dips strongly suggest the presence of a shallow buried Precambrian hill in this area.

Peripheral dips of the Caledonia area resemble those of other areas, but are somewhat more gentle. In the other areas dips are as high as 30 degrees. Factors responsible for the relatively low dips will be discussed in the final chapter.

Joint Patterns

Joints were mainly exposed at four localities in this area. About twenty vertical joints were noted in the bed of the small stream that flows northward parallel to Missouri Highway 21 in the northeastern quarter of the area. Numerous joints crop out in the bed of a small stream immediately northeast of the northern end of the large rhyolite porphyry ridge. Other joints are exposed in Reynolds Branch in the southeast quarter of the area and north and south of Aker Hill in the southwest quarter of the area.

In the stream parallel to Missouri Highway 21, the northernmost joints show a generally northward trend. Southward the joints have a generally eastward and northeastward strike. The northeast joints are particularly prominent near the small rhyolite porphyry exposures. Figures 62 and 63 show the development of the northeast trending joints about 1,000 feet north of the two small rhyolite porphyry exposures.

In the immediate vicinity of the small rhyolite porphyry exposures, the joints are more irregular, but in general parallel the margins of the exposures.

Joints in the small stream near the northeast end of the large rhyolite porphyry ridge show a more irregular pattern, with northeast and northwest strikes. These occur where dips of strata vary locally adjacent to a suspected buried Precambrian hill. The relationship of these joints to the suspected buried hill is not clear.

North and south of Aker Hill, joints generally parallel the outline of the Precambrian exposure. About 2,500 feet north of Aker Hill, a very strong set of vertical joints strikes perpendicular to the gross outline of the hill, while a less prominent joint set strikes parallel to the outline of the hill (Figure 64 and 65).

Figure 61. Lamotte Formation about 200 feet west of Missouri Highway 21, and less than 400 feet from exposed rhyolite porphyry. Dips 7 degrees toward the north (about 3,700 feet north of Valley High School).

Figure 62. Strong, well-defined vertical joints in Bonneterre Formation. These joints strike N. 55° E., approximately parallel to an inferred buried Precambrian ridge line (about one mile north of Valley High School). Nearby rhyolite porphyry exposures show no joints.

Figure 63. Same area shown in Figure 61, with more parallel joints visible to the left, indicated by lines of vegetation in the stream.

Figure 64. Thin-bedded and shaly facies of the Bonneterre Formation with strong vertical joint set across stream, N. 67° E., approximately perpendicular to the outline of Aker Hill to the south. Less prominent vertical joint set strikes N. 16° W. (2,500 feet north of the crest of Aker Hill).

Figure 65. Six parallel vertical joints, N. 67° E., perpendicular to the outline of Aker Hill to the south. Less prominent joint set strikes parallel to direction of flow of stream (same locality as Figure 64).

Inferred Trends of Buried Precambrian Ridges

Based on available geological and magnetic data, five buried Precambrian ridges are inferred in the Caledonia area (Figure 57). Four are closely related to the large exposed Precambrian ridge that extends northeastward through the area. The fifth is related to a small rhyolite porphyry exposure immediately north of Caledonia. This may be an eastward extension of rhyolite porphyry exposed at Aker Hill.

Evidence for the ridge from Kitchell Hill includes two exposures of rhyolite porphyry, the strike and dip of sedimentary rocks, the trend of vertical joints, and a prominent magnetic anomaly along the trend of the ridge. Both rhyolite porphyry exposures are relatively small, but are associated with more extensive exposures of the Lamotte Formation. Sedimentary units directly north of the ridge dip generally at a low angle toward the northwest, away from the inferred strike of the ridge. In the immediate vicinity of the rhyolite porphyry exposures, dips are in various directions, but always away from the exposures. This suggests the small igneous exposures are small knobs on a buried ridge.

The prominent joints shown in Figures 62 and 63 strike N. 55°E., approximately parallel to the inferred Precambrian ridge lines. Other joints strike generally northeastward and eastward.

A closed magnetic anomaly with a relative magnitude of more than 50 gammas is associated with these small rhyolite porphyry exposures. The anomaly has absolute value of 2,330 gammas at its crest (Figure 56). This closure is on the trend of a magnetic nose that generally corresponds with the inferred trend of the buried Precambrian ridge.

A second inferred buried Precambrian ridge extends northeastward from the large exposed Precambrian ridge at a point about 4,000 feet north of Missouri Highway C. Evidence for the inferred ridge is the pronounced reversal of dips in the area, suggesting a shallow depth origin. About half the joint sets mapped in this area strike northeast, roughly parallel to the trend of the inferred ridge.

Another buried Precambrian ridge is suggested immediately north of the one described above, by a relatively extensive exposure of the Lamotte Formation in an area where the Bonneterre Formation should normally crop out. A prominent magnetic nosing to the northeast (Figure 56) coincides with the trend of this inferred Precambrian ridge.

A fourth inferred buried Precambrian ridge is indicated on the northern tip of the large exposed Precambrian ridge. This buried ridge is suggested in part by the trend of the exposed Precambrian ridge and also by a prominent magnetic nose which corresponds closely with the inferred trend (Figure 56).

A fifth suggested buried Precambrian ridge extends westward from a rhyolite porphyry exposure just north of the city of Caledonia. This inferred buried ridge is partly based on the disappearance of rhyolite porphyry and Lamotte Formation toward the west. Unusually widely spaced magnetic contours at a point about half way between the small exposure of rhyolite porphyry, and Aker Hill to the west, further suggests the presence of a buried Precambrian ridge line.

MAGNETIC CHARACTERISTICS OF THE AREA

Total magnetic field strength in the Caledonia area is about

56,800 gammas, or 0.568 gauss. Inclination of the total field is about $68^{o}45'$ (U. S. Coast and Geodetic Survey, 1955). This area (Figure 55) is included in a total intensity aeromagnetic survey of the Potosi quadrangle (U. S. Geological Survey, 1950).

Magnetic susceptibility of 0.817×10^{-3} cgs units was determined for rhyolite porphyry taken from the base of the highway where Missouri Highway C crosses north of Kitchell Hill. This susceptibility falls within the range of those presented by Allingham (1964, p. 543) for rhyolite of the St. Francois Mountains. However, it is lower than those determined by the writer for the granite of Czar Knob (1.147×10^{-3} cgs units) and the trachyte porphyry of Little Pilot Knob (5.250×10^{-3} cgs units).

In spite of the relatively low magnetic susceptibility of the rhyolite porphyry of the Caledonia area, anomalies of the aeromagnetic map (Figure 56) show fair correspondence to both the known and the geologically inferred Precambrian topography. A prominent northeast trending magnetic anomaly corresponds with the large exposed rhyolite porphyry ridge of the area. The greatest value (2,815 gammas) of magnetic intensity along the ridge lies immediately south of the crest of Aker Hill which is also the highest point on the ridge. The least elevation on the exposed Precambrian ridge, just north of Kitchell Hill, likewise corresponds closely with the minimum value of magnetic intensity.

A second closed anomaly with a maximum value of 2,540 gammas is at the northern tip of the exposed igneous ridge. This anomaly does not correspond with an unusually high point on the exposed Precambrian ridge line. Its magnitude might be due in part to combined influence of three geologically inferred buried Precambrian ridges that extend from the exposed ridge at this location. It could also be due to change in magnetic susceptibility.

A prominent magnetic trend extends northeastward from the area just north of Kitchell Hill on the geologic map. The inferred ridge associated with this anomaly is discussed in an earlier section. A small closure with a value of 2,330 gammas is located on this trend. This closure lies immediately south of two small exposures of rhyolite porphyry. This magnetic trend is indicated to be associated with the geologically inferred buried ridge that extends northeastward through the area.

A closed magnetic anomaly with a value of 2,335 gammas is about 4,000 feet west of the northern tip of the large exposed igneous ridge and near Big River. Because this area is largely covered by alluvium, few geologic data are available to confirm the presence of a buried Precambrian hill here. The few sedimentary outcrops observed in the area are essentially flat-lying. The broadness of this anomaly and low amplitude suggests a buried hill, if present, would lie well below the surface.

The small rhyolite porphyry exposure immediately north of Caledonia is indicated only by local widely spaced magnetic contours. This area of widely spaced contours extends generally westward toward Aker Hill and suggests a possible buried Precambrian ridge line in this area.

SUMMARY AND CONCLUSIONS

A three mile long northeast trending ridge of rhyolite porphyry is an outstanding geologic feature of the Caledonia area. Three much smaller rhyolite porphyry knobs (less than forty acres) are also exposed. The igneous exposures are entirely surrounded by the Lamotte and Bonneterre formations. The rhyolite porphyry is generally less porphyritic than where observed in other areas. The Lamotte Formation is typically thin-bedded and arkosic sandstone. However, a few outcrops of the unit are medium-bedded and nearly free of arkosic material. The Bonneterre Formation is generally medium to thick-bedded and fairly pure light gray crystalline dolomite. In the transition zone with the underlying Lamotte Formation, the unit is sandy and thin-bedded. A limestone and rhyolite porphyry conglomerate occurs in the basal part of the Bonneterre Formation at one locality.

Cross-bedding and arkosic material of the Lamotte Formation suggest a shallow marine environment of deposition. Much of the arkosic material appears to have been locally derived. A gradual, partly interrupted trend toward a deeper marine environment is indicated by an increase in carbonate deposition. The nearly pure, arkose-free dolomite of the Bonneterre Formation suggests a deeper marine environment in which the rhyolite porphyry ridges were submerged below wave base.

Peripheral sedimentary rock dips range to a maxiumu of 12 degrees. The higher dips are generally adjacent to Precambrian exposures. These peripheral dips are similar to those in other areas, but are unusually low. Vertical joint sets at four general localities in the Caledonia area generally strike either parallel or perpendicular to the outline of adjacent Precambrian exposures. In a few instances, no clear relationship can be recognized.

Five buried Precambrian ridges are inferred in the Caledonia area and are supported by both geologic and magnetic evidence. The longest of these ridges extends northeastward across the Caledonia area, and has two small exposures of rhyolite porphyry along its trend.

Three crushed samples of rhyolite porphyry yielded an average magnetic susceptibility of 0.817×10^{-3} cgs units. In spite of a relatively low susceptibility, a general correspondence is indicated between magnetic anomalies on the aeromagnetic map (Figure 56) and outcrops of rhyolite porphyry on the geologic map.

THE SULLIVAN AREA

INTRODUCTION

The Sullivan area is about sixty miles north of extensive Precambrian igneous exposures of the St. Francois Mountains, in a region of nearly flat-lying sedimentary rocks composed of early Ordovician Roubidoux and Gasconade formations. No igneous outcrops are known, but a drill hole in the northwest quarter of section 18, T. 40 N., R. 2 W., cut rhyolite porphyry at a depth of 25 feet (Figure 68). With the exception of isolated trachyte porphyry exposures at Little Pilot Knob (eighteen miles southwest), the nearest known igneous exposures lie nearly thirty miles to the south.

The general area around Sullivan has experienced considerable geologic and geophysical activity within the last several years due to discovery of high grade iron ore deposits within the Precambrian basement.

LOCATION, SIZE, AND ACCESSIBILITY OF THE AREA

The Sullivan area is sixty miles southwest of St. Louis, Missouri, and includes the western portion of the city of Sullivan. The area selected is rectangular, about two miles wide and three miles long and is crossed northeasterly by U. S. Highway 66. Numerous other good secondary roads, both paved and unpaved, make most of the area readily accessible by automobile.

PREVIOUS WORK

Aid (1937) completed a generalized geologic structure map of the

Bourbon-Sullivan, Missouri, area. Searight, Williams, and Hendrix (1954) published results of their magnetic and geologic structure studies of the Sullivan-Bourbon, Missouri, area. Dempsey and Meuschke (1951) published a total intensity aeromagnetic survey of the Sullivan quadrangle and part of the Union quadrangle. No other published work is known for the area.

GEOLOGIC SETTING OF THE AREA

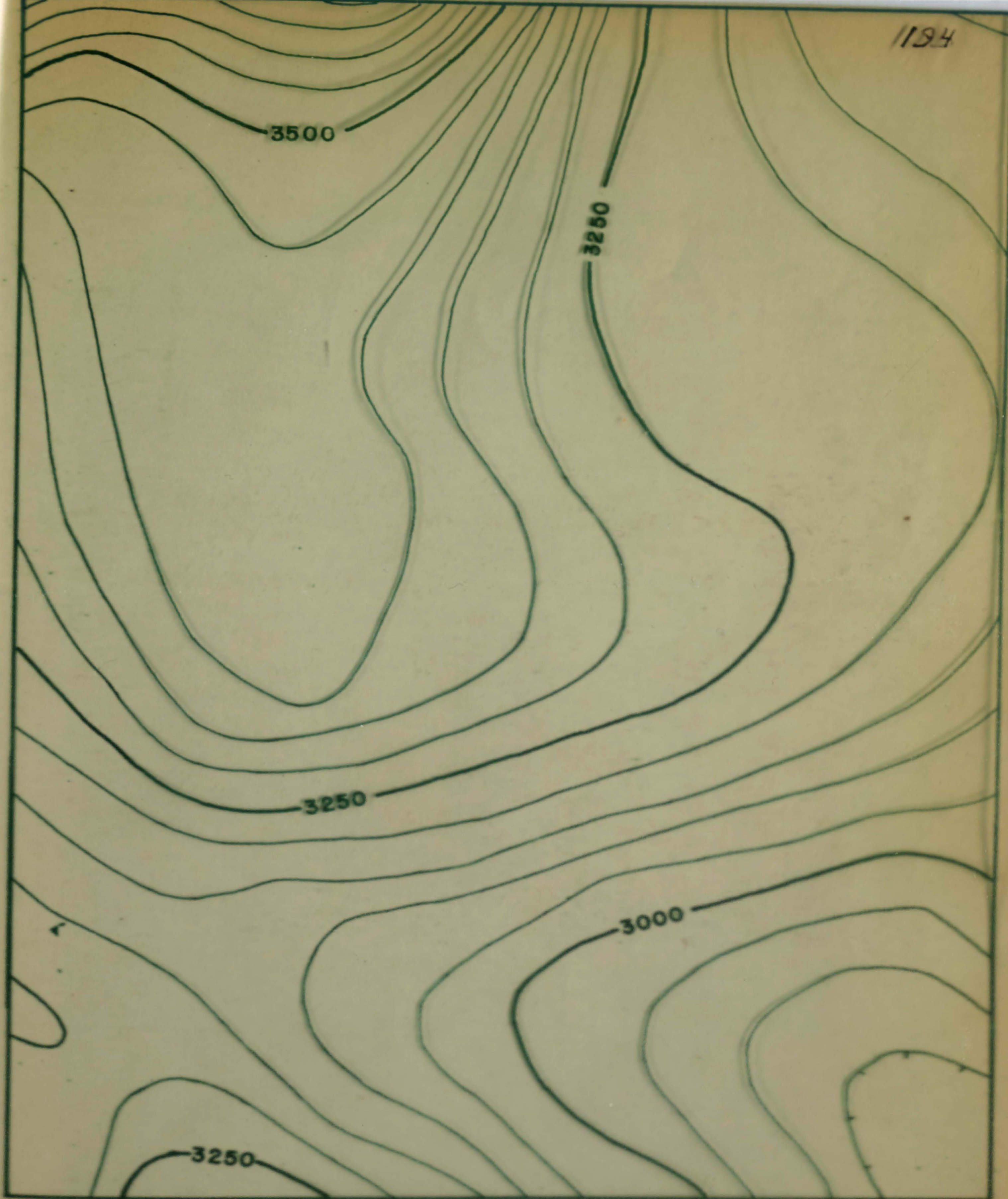
The Roubidoux and Gasconade formations crop out in the Sullivan area. The Roubidoux Formation is at the surface in about 80 percent of the area, while the Gasconade Formation crops out in small areas in the northern and southeastern parts. Outcrops are generally scarce, but locally are abundant and extensive in the southeast corner of the area in a relatively deep valley cut into the Gasconade Formation. Much of the area is covered by thick residuum, soil, and dense vegetation.

No Precambrian outcrops are known, though as noted, rhyolite porphyry was cut in a drill hole at twenty five feet in the central part of the area.

Geomorphology

The Sullivan area is predominantly one of low relief. Only where stream erosion has cut deeply into the Gasconade Formation in the southeastern part, has a limited area of medium relief developed.

The area is mainly a part of a nearly flat, upland plateau capped by sandstone beds of the Roubidoux Formation. Streams flowing on this resistant sandstone formation have very shallow open valleys. To the south and southeast streams have cut through the Roubidoux Formation and



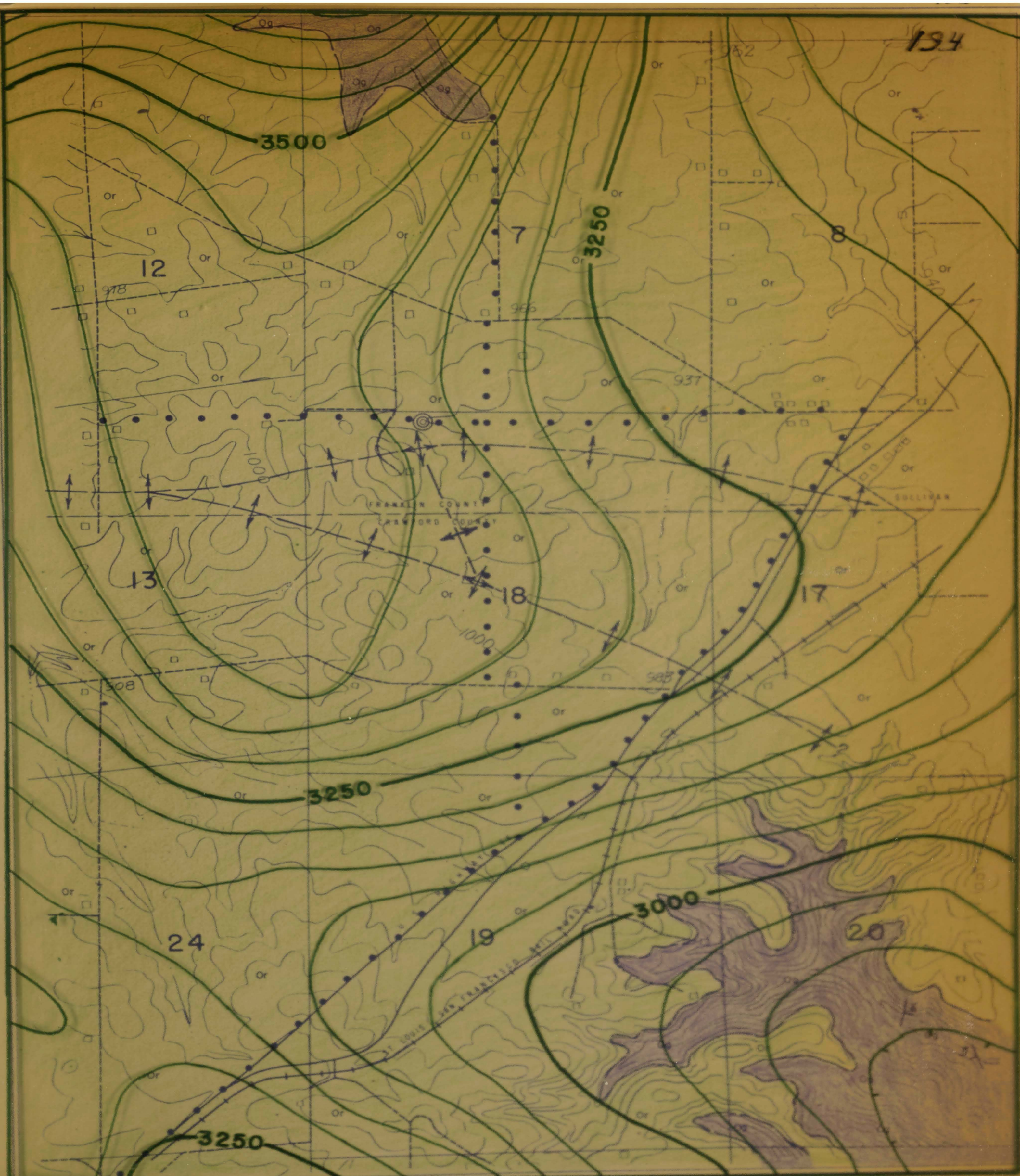
TOTAL INTENSITY AEROMAGNETIC MAP OF THE SULLIVAN AREA

CONTOUR INTERVAL 50 GAMMAS

FROM TOTAL INTENSITY AEROMAGNETIC MAP OF SULLIVAN QUADRANGLE AND PART OF UNION QUADRANGLE, MISSOURI U.S.G.S. MAP GP 78 1951

FLIGHT ELEVATION: 1,800 FEET ABOVE SEA LEVEL

FIGURE 66



TOTAL INTENSITY AEROMAGNETIC MAP OF THE SULLIVAN AREA
CONTOUR INTERVAL 50 GAMMAS
FROM TOTAL INTENSITY AEROMAGNETIC MAP OF SULLIVAN QUADRANGLE AND PART OF UNION QUADRANGLE, MISSOURI U.S.G.S. MAP GP 78 1951
FLIGHT ELEVATION: 1,800 FEET ABOVE SEA LEVEL
FIGURE 66

135
195

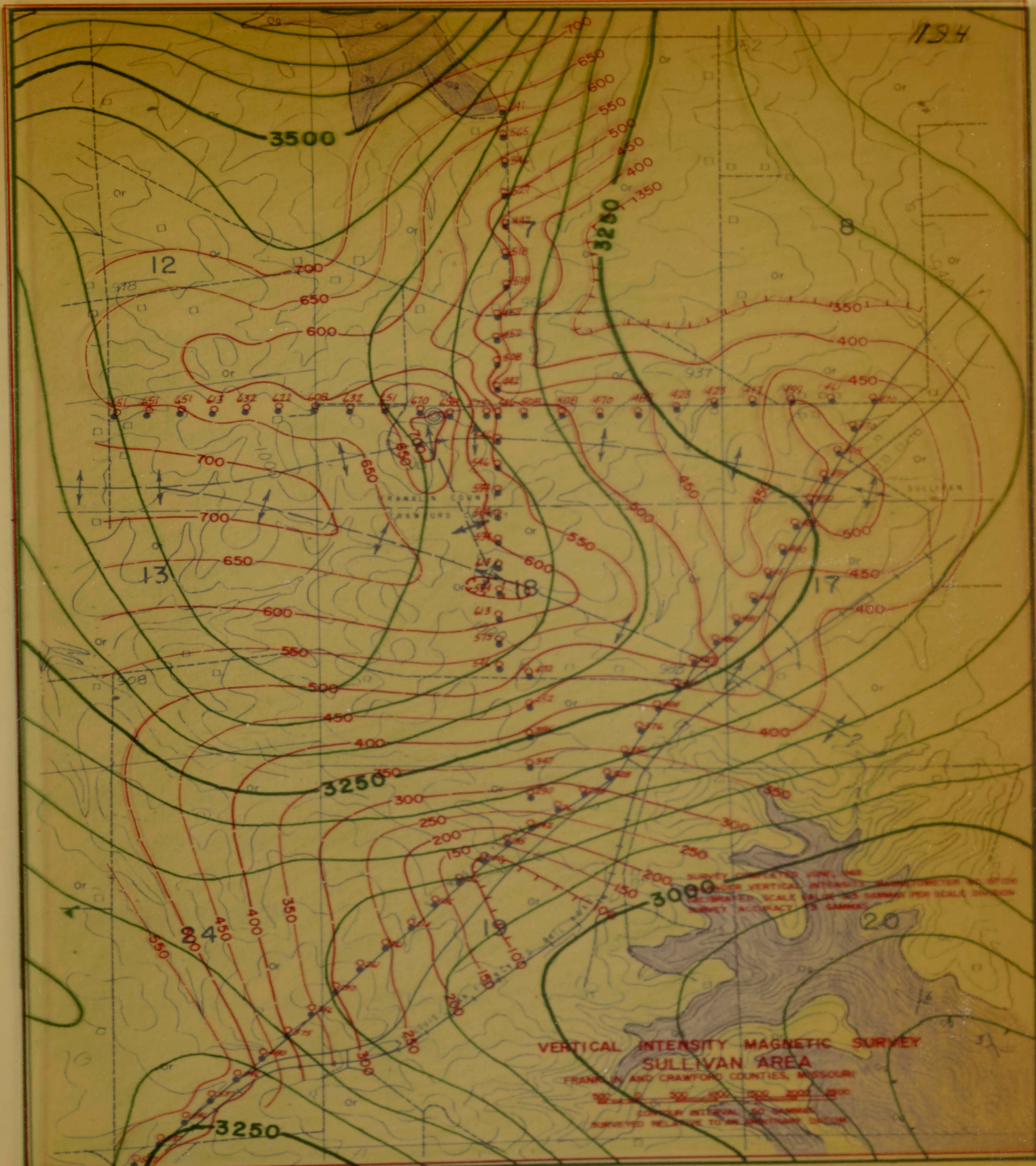
BASE FROM U. S. GEOLOGICAL SURVEY
TOPOGRAPHIC SHEET SULLIVAN, MO.
TOWNSHIP 40 NORTH, RANGES 2 & 3 WEST

GEOLOGIC MAP OF THE
SULLIVAN AREA
FRANKLIN AND CRAWFORD COUNTIES, MISSOURI

FIGURE 67

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

FIGURE 68



TOTAL INTENSITY AEROMAGNETIC MAP OF THE SULLIVAN AREA
CONTOUR INTERVAL 50 GAMMAS
FROM TOTAL INTENSITY AEROMAGNETIC MAP OF SULLIVAN QUADRANGLE AND PART OF UNION QUADRANGLE, MISSOURI U.S.G.S. MAP GP 78 1951
FLIGHT ELEVATION: 1,800 FEET ABOVE SEA LEVEL
FIGURE 66

GEOLOGIC MAP OF THE SULLIVAN AREA
FRANKLIN AND CRAWFORD COUNTIES MISSOURI
FIGURE 67

FIGURE 68

formed deeper and more narrow valleys and high ridges in the Gasconade Formation. The relatively deep valley in the southeastern corner of the selected Sullivan area marks the beginning of this region of valleys and ridges.

The St. Louis and San Francisco Railroad right-of-way marks the location of a drainage divide in the Sullivan area. Streams to the north of the right-of-way flow generally northward and westward and empty into the Bourbeuse River. South of the right-of-way, streams flow generally to the southeast, and empty into the Meramec River.

STRATIGRAPHY OF EXPOSED FORMATIONS

The Gasconade Formation crops out extensively in the southeastern part of the area. A small outcrop of the formation probably occurs at the northern boundary of the Sullivan area, based on the presence of Gasconade Formation residuum in a small stream. The Roubidoux Formation is generally poorly exposed in the area and only a few widely spaced outcrops were noted. Sandstone residuum from the formation is likewise scarce, but is more abundant than outcrops.

Gasconade Formation

Only the uppermost 100 feet of the Gasconade Formation is exposed in the Sullivan area. A Cryptozoon chert bed, described in the area by Searight, Williams, and Hendrix (1954, p. 7), is about fifty feet below the top of the formation. It is poorly exposed in the area, but outcrop areas are indicated by blocks of chert float. A good exposure of the formation is in and adjacent to a stream near the center of the west half of section 20. A description of this outcrop follows:

Dolomite, light gray, medium crystalline, thin to medium-bedded, partly irregularly bedded, cherty; chert, light gray to white, dull, generally nodular, comprises about 20 percent of outcrop. Abundant chert residuum in area of outcrop. Beds dip 6 degrees east, strike N. 10°E...15' 0"

The contact between the Gasconade Formation and the overlying Roubidoux Formation is not well exposed in this area. Searight, Williams, and Hendrix (1954, p. 9) report the contact is unconformable, and describe a local chert conglomerate at the base of the Roubidoux Formation. For this work the contact is approximately located, and is based on the lowest identifiable sandstone beds of the Roubidoux Formation.

Roubidoux Formation

The Roubidoux Formation crops out at a few widely scattered localities in the Sullivan area. Elsewhere its presence is demonstrated by abundant sandstone residuum. Over much of the area, however, the formation is entirely concealed by thick residuum and vegetation.

On weathered surfaces, sandstone of the Roubidoux Formation is a distinctive bright, orange-brown. Where fresh it is light brown to light gray. The sandstone is generally fine to medium-grained, well-sorted, and is commonly cross-bedded and ripple-marked. Locally, cross-bedding and ripple marks suggest a northeasterly source. Individual sand grains consist of subrounded to angular quartz, with ferruginous clay cement. A generally typical outcrop of the formation in the Sullivan area on a secondary road near the center of the north half of section 24 has the following characteristics:

Sandstone, bright, orange-brown, light gray where fresh, medium-grained, well-sorted, with ferruginous clay cement; compact, medium-bedded, partly cross-bedded and ripple-marked; northeasterly source of sediments indicated. Beds are essentially flat-lying..........................6' 0"

DEPOSITIONAL ENVIRONMENT OF THE AREA

Outcrops of the Gasconade and Roubidoux formations in the Sullivan area are essentially similar to those observed elsewhere in the Central Ozarks. Evidences of the type of depositional environment include an abundance of algal material in the upper part of the Gasconade Formation and cross-bedding and ripple marks in the Roubidoux Formation.

The abundance of algal material suggests a shallow, clear water environment. The cross-bedding and ripple marks in the Roubidoux Formation suggest very shallow water conditions existed in the Sullivan area during the deposition of these clastic beds.

The meager field evidence suggests the buried Precambrian hill encountered in drilling in the Sullivan area had little influence upon the sedimentary environments in this area. Yet, because no outcrops are present in the immediate vicinity of the buried hill, nothing is known of the local sedimentary conditions. Presumably they should resemble those of other areas of isolated islands in a marine environment.

Carver, (1961, p. 90) recognizes a back-reef lagoon facies which includes the general region of Sullivan, Missouri. He indicates this facies contains more than 30 percent sand and is the zone of maximum sand accumulation for the Roubidoux Formation. According to paleocurrent studies by Carver (p. 87), the source of clastic sediments in the Sullivan, Missouri, region was to the northeast. The few observations of cross-bedding and ripple marks in the Sullivan area tend to support Carver's conclusions.

STRUCTURE OF THE AREA

Local dips as high as 6 degrees were noted at two localities in the southeastern part of the area. Elsewhere, outcrops were generally too poorly exposed, or dips too low to be measured with accuracy.

No joints were observed in the Sullivan area. In other areas, essentially all mapped joints were located in stream beds. In this area, almost without exception, they are filled with colluvial material.

Drainage Patterns of the Area and Structure

Because the direction of streams in the Sullivan area appear to be strongly influenced by the general dip of resistant sandstone beds of the Roubidoux Formation, an overlay of the geologic map showing only drainage patterns was prepared (Figure 69).

Four localities where drainage maybe influenced by structure are identified in the Sullivan area. Area I (Figure 69) includes the locality where rhyolite porphyry was cut at a depth of twenty five feet. Small streams drain north, northeast, east, west and southwest from Area I. Because the streams appear to have their courses influenced by the dip of sandstone beds of the Roubidoux Formation, a low dome lacking closure only to the south and southeast is suggested.

Area II lies immediately southeast of Area I. Here streams flow to the east, west, and south. This configuration suggests Areas I and II may define a local northwesterly trending anticline.

Area III is immediately southwest of Sullivan. Here streams flow generally east, northeast, and west, and suggest a somewhat elongate, northward trending anticline.

Area IV is southwest of Area III, and appears to be a continuation

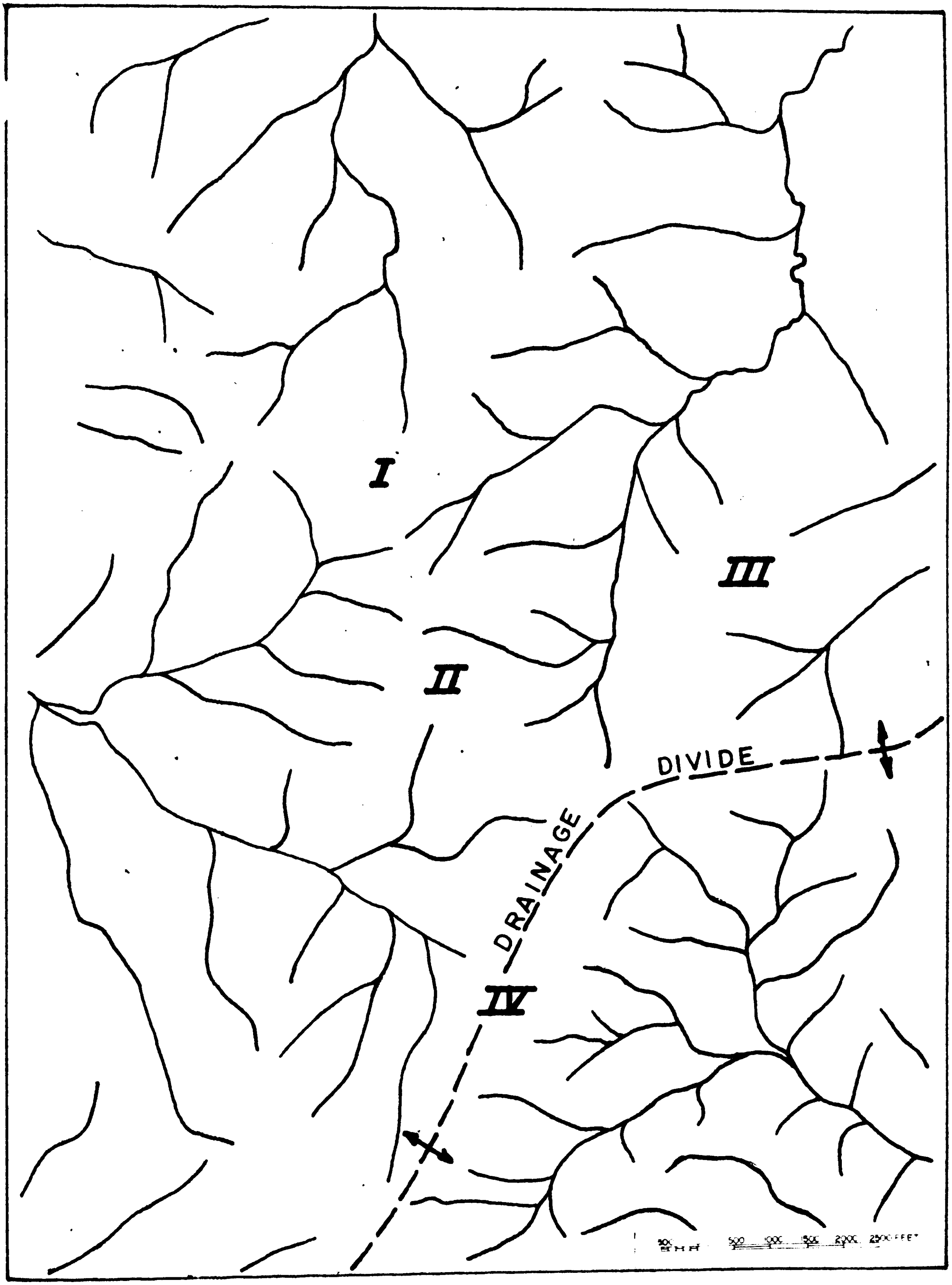


FIGURE 69. DRAINAGE PATTERNS OF THE SULLIVAN AREA

WITH ANOMALOUS AREAS INDICATED BY ROMAN NUMERALS. SEE TEXT FOR DISCUSSION of the anticlinal ridge suggested by drainage patterns for Area III. Area IV is a drainage divide. Drainage patterns to the southeast of Area IV are not influenced by sandstone beds of the Roubidoux Formation, as streams here have cut through the formation, and flow on units of the Gasconade Formation. The Area IV drainage pattern may have no structural significance.

MAGNETIC CHARACTERISTICS OF THE AREA

The total magnetic field strength in the Sullivan area is about 57,100 gammas or 0.571 gauss. The inclination of the total field is about 69 degrees (U. S. Coast and Geodetic Survey, 1955).

The Sullivan area is included in the total intensity aeromagnetic survey of the Sullivan quadrangle. The portion of this map that includes the selected Sullivan area is shown in Figure 66. The aeromagnetic map shows a broad, southward trending nose, in the western part of the area. An area of low magnetic intensity is indicated in the southeastern corner of the Sullivan area. No closure is present where rhyolite porphyry was cut at a depth of twenty five feet. The writer completed a detailed vertical intensity magnetic survey over a major part of the area (Figure 67).

The latter survey shows an anomalous eastward trending area of higher magnetic intensity in the central portion of the Sullivan area. Magnetic intensity decreases both to the northeast and south from this area. Two closed anomalies are present. The first lies immediately south of the point where rhyolite porphyry was cut at a depth of twenty five feet. This anomaly has a magnitude of approximately 75 gammas. The sharpness of the northeast flank of this anomaly indicates a near-surface origin.

Using Jakosky's equation (Jakosky, 1960, p. 213), the source of the anomaly is no deeper than 200 feet. This suggests that the drill hole that cut rhyolite porphyry at twenty five feet may have been fortuitously located at or near the highest point of the buried rhyolite porphyry hill. If extensive portions of the hill were at a depth of twenty five feet, a much stronger and sharper anomaly would be expected.

A second closed anomaly is near the eastern boundary of the Sullivan area, and near the southeast part of the city of Sullivan. The broader character of this closed anomaly suggests that it lies at a greater depth than the one described above. Using Jakosky's equation, the source of the anomaly is indicated at about 500 feet below the surface.

If the broad area of higher magnetic intensity containing the two above anomalies is treated as one aggregate anomaly, an approximate depth can be calculated for its source. Using Jakosky's equation, the source of this broad area of higher magnetic intensity is indicated to be at a depth of more than 1,000 feet.

From Jakosky's equation, magnetic data suggest the presence of a buried Precambrian ridge lying generally at a depth of more than 1,000 feet. This relatively broad ridge appears to have at least two prominences or hills, one of which rises to within about 500 feet of the surface.

INFERRED TRENDS OF BURIED PRECAMBRIAN RIDGES

Inferences regarding the configuration of the buried Precambrian surface are based upon results of a magnetic survey in the Sullivan area (Figure 66), and the study of drainage patterns developed in the Roubidoux

Formation (Figure 69).

The magnetic survey suggests the presence of eastward and southeastward trending ridges through the central part of the Sullivan area. These ridges appear to be part of a larger eastward trending ridge system. Possible buried hills situated on this ridge system are suggested by closed magnetic anomalies in the northwest part of section 18 (where rhyolite porphyry was encountered at a depth of twenty five feet), and in the northern part of section 17.

Drainage anomalies I and III (Figure 69) also suggest buried Precambrian hills in the northwest quarter of section 18. Drainage anomaly III coincides with the magnetic anomaly in the northern part of section 17.

Drainage anomaly IV may have no direct relationship to the buried Precambrian topography as it is located in an area of very low magnetic intensity.

The Sullivan area is included in a much larger area of about 250 square miles, for which a geologic structure map was prepared by Searight, Williams, and Hendrix (1954). Their map is contoured on the base of the _Cryptozoon_ chert bed in the upper part of the Gasconade Formation, with a scale of 1:63360, and a contour interval of fifty feet. Their map shows a westward-plunging, shallow syncline extending from south of Sullivan, and westward across the central part of the Sullivan area. The drill hole in which rhyolite porphyry was cut at a depth of twenty five feet lies directly in the trough of this syncline. The structure map shows a low anticline in the northeastern part of the Sullivan area, and a generally northwestward plunging anticline in the southeastern part of the area.

The structure shown on the map by Searight, et al., for the Sullivan area does not appear to be in good agreement with structure inferred in the preceeding paragraphs, from examination of drainage patterns. Northward drainage away from the syncline, and up-dip toward the crest of the anticline in the northeastern part of the Sullivan area is indicated. In the southeastern part of the Sullivan area, drainage is toward the southeast and again up-dip, along the crest of the northwest plunging anticline.

If the structure map is correct, streams of the Sullivan area are very poorly adjusted to structure, and conclusions drawn in this study from the drainage pattern analysis may not be valid. However, based upon observations made in other areas of this study, the writer believes a low anticline or dome is likely to be present where rhyolite porphyry is encountered at twenty five feet. This appears to be supported by configuration of drainage patterns of the Sullivan area.

SUMMARY AND CONCLUSIONS

The Sullivan area is on an upland plateau formed on nearly flat-lying sandstone of the Roubidoux Formation. Only sedimentary rocks of the Roubidoux and Gasconade formations are known to crop out in the area. However, within the central part of the area rhyolite porphyry was cut in drilling at a depth of twenty five feet.

Units of the Gasconade and Roubidoux formations in the Sullivan area are essentially similar to those seen elsewhere in the Central Ozarks. A shallow to very shallow marine environment probably existed in the

Sullivan area during deposition of the Gasconade and Roubidoux formations. Meager field evidence suggests the buried Precambrian hill had little influence upon depositional environments of the area. Nothing is known of sedimentary conditions that existed in the immediate vicinity of the buried hill. Carver (1961) reports a back-reef lagoon facies in the Roubidoux Formation in the general region of Sullivan, Missouri, and indicates a northeasterly source for the clastic sediments.

Because of very low dips of the sandstone beds of the Roubidoux Formation, and a general scarcity of outcrops, structure of the area is largely inferred by analysis of drainage patterns formed on the resistant sandstone beds. Two drainage anomalies are recognized in the general area where rhyolite porphyry was encountered at a depth of twenty five feet.

A third drainage anomaly is recognized at the southeastern margin of the city of Sullivan. A fourth drainage anomaly is recognized in the south-central part of the Sullivan area.

A geologic structure map by Searight, Williams, and Hendrix (1954) shows a shallow syncline where rhyolite porphyry was cut at twenty five feet in the Sullivan area. If this map is correct, the streams of the area are poorly adjusted to structure, and the recognized drainage patterns may have no structural significance.

The aeromagnetic map of the Sullivan area (Figure 65) shows a broad, southward trending magnetic nose in the western part of the area, and an area of low magnetic intensity in the southeastern part.

Results of a detailed vertical intensity magnetic survey of the Sullivan area suggest the presence of two generally eastward trending, closely adjacent buried Precambrian ridges in the Sullivan area. Three of the drainage anomalies lie along the trend of these inferred ridges. A fourth drainage anomaly may have no direct relationship to buried Precambrian topography.

By use of simple magnetic depth calculations, the buried Precambrian surface is indicated to be at a depth of about 200 feet in the area where rhyolite porphyry was encountered in a drill hole at twenty five feet. It seems probable that this drill hole was fortuitously located at or near the highest point of the buried rhyolite porphyry hill.

The source of a second magnetic anomaly, near the southwestern part of the city of Sullivan, is indicated to be at a depth of about 500 feet.

The above two anomalies are located in broad area of higher magnetic intensity that coincides with the location of the two inferred eastward trending buried Precambrian ridges. The source for this area of higher magnetic intensity is indicated to be at a depth of more than 1,000 feet below the surface.

USE OF THE SURFACE INTEGRAL METHOD IN COMPUTATION OF THEORETICAL TOTAL INTENSITY AEROMAGNETIC ANOMALIES FOR TWO PRECAMBRIAN HILLS

INTRODUCTION

An important method for the interpretation of a magnetic anomaly is its comparison (shape and magnitude) with anomalies calculated for simple geometric forms. If a good overall comparison is found, it is assumed that the geologic body producing the anomaly may have a similar magnetic susceptibility, shape, and depth of burial as does the theoretical body producing the comparable calculated anomaly. This procedure is generally known as the standard indirect method of magnetic interpretation. Vacquier et al, (1951) have calculated a large number of anomalies for simple geometric bodies having different dimensions, and having been set up for different inclinations and orientations with respect to the external magnetic field.

In the present work, the surface integral method is used to calculate theoretical aeromagnetic anomalies above a partly buried Precambrian hill whose configuration is fairly well known (Czar Knob), and above a second partly buried Precambrian hill whose configuration is only partly known (Little Pilot Knob). The theoretical aeromagnetic anomalies produced through these calculations are compared with the actual anomalies obtained by aeromagnetic surveys over the respective hills.

Most previous calculations of theoretical anomalies have been completed through use of volume integration, rather than surface integration. Volume integration involves considerable computation time, and because of the complexity of the method, only simple geometric forms are commonly used.

The surface integral method is described in detail by Saad (1962). The body for which calculations are to be made is considered to have two surfaces. The magnetic intensity produced by the lower surface is subtracted from that resulting from the upper surface in order to obtain an approximation of the anomaly produced by the body.

Saad calculates total magnetic intensity for a number of simple geometric models, and compares his results with those of Vacquier *et al*. He reports excellent agreement in absolute values of total intensity when the inclination of the magnetic field is 90 degrees. As magnetic inclination is decreased toward 45 degrees, he reports the total intensity field is shifted slightly northward relative to that calculated by Vacquier *et al*, and a slight decrease in absolute magnitude of the field is noted. Saad (1962, p. 59) concludes that the surface integral method can be used to calculate magnetic anomalies due to three-dimensional bodies in a minimum of time with an accuracy adequate for most purposes. He reports that the error may become significant at inclinations of the earth's magnetic field of less than 60 degrees.

Because inclination of the earth's total field is greater than 60 degrees in both the Czar Knob and the Little Pilot Knob areas, the surface integral method should produce useful results.

APPLICATION OF THE SURFACE INTEGRAL METHOD IN COMPUTATION OF ANOMALIES ASSOCIATED WITH BURIED PRECAMBRIAN HILLS

The surface integral method, in its application to buried

Precambrian hills, involves the division of the hill into a large number of vertical dipoles. (The greater the number of dipoles, the more accurately the configuration of the buried hill is reproduced.) The upper surfaces of the dipoles are at various elevations, and correspond with the elevation of the upper surface of the buried hill. The bases of all dipoles are at the same level, and correspond with the elevation of the base of the buried hill.

The problem resolves itself into the calculation of the magnetic field at a point in space above the buried hill, produced by one of the component vertical dipoles of the buried hill. Subsequently, identical calculations of magnetic intensity are made successively for all other vertical dipoles. The results of these calculations are algebraically added to give the magnetic intensity for a single point in space above the buried hill. Then, additional points at the same elevation above the hill are selected until a sufficient number have been calculated to prepare a contoured map of the magnetic field for a selected elevation above the buried hill.

Equations used for the calculations of magnetic intensity at a single point in space, as modified after Saad (1962, p. 21), are as follows:

$$\triangle H = Hk\Delta A \cos\theta \; \frac{(x' - x)}{\left[(x' - x)^2 + (y' - y)^2 + (z')^2\right] 3/2} - \frac{(x' - x)}{\left[(x' - x)^2 + (y' - y)^2 + (h)^2\right] 3/2}$$

and:

$$\triangle V = H\, k\Delta A \cos\theta \; \frac{z'}{\left[(x' - x)^2 + (y' - y)^2 + (z')^2\right] 3/2} - \frac{z'}{\left[(x' - x)^2 + (y' - y)^2 + (h)^2\right] 3/2}$$

and:

$$\Delta T = \Delta H \sin \theta + \Delta V \cos \theta$$

where:

ΔH = horizontal intensity due to a single dipole

ΔV = vertical intensity due to a single dipole

ΔT = total intensity due to a single dipole

and:

H = earth's total field at locality of calculation

k = is magnetic susceptibility of rock material of buried hill

ΔA = cross-sectional area of vertical dipole, expressed in square centimeters

θ = complement of the angle of inclination of earth's magnetic field

x = distance measured northward in centimeters to a selected point from a selected arbitrary origin lying in a plane above a buried hill

y = distance measured eastward in centimeters to a selected point from a selected arbitrary origin lying in a horizontal plane above a buried hill

x' = distance measured northward, in centimeters, from a selected arbitrary origin to the center of a vertical dipole of the buried hill

y' = distance measured eastward, in centimeters, from a selected arbitrary origin to the center of a vertical dipole of the buried hill

z' = is the vertical distance measured in centimeters, from the plane (x,y) to the top of a vertical dipole.

h = vertical distance measured in centimeters from the plane (x,y) to the bottom of all vertical dipoles.

As the foregoing equations are derived by Saad, no further elaboration will be considered here.

BASIC ASSUMPTIONS AND LIMITATIONS OF THE SURFACE INTEGRAL METHOD

Probably the most significant limitation of the surface integral method is that only vertical polarization is assumed. This assumption would hold true only if the inclination of the earth's total field were vertical. The error introduced by this simplifying assumption becomes greater as the earth's total field becomes less steeply inclined. The most serious effect of this assumption is that the calculated field will be shifted slightly northward from its true position. Because horizontal polarization is neglected, the computed field strength will be slightly less than its true value. Both of these factors become insignificant at inclinations of the earth's total field of more than 60 degrees.

A second simplifying assumption is that the buried hill is homogeneous; that is, magnetite content and corresponding magnetic susceptibility are considered to be uniform throughout. This assumption appears reasonable for the relatively small geologic bodies of this study. Considerable error might arise where important variations in magnetic susceptibility are present.

Remnant magnetism is not considered in this application of the surface integral method. Allingham (1964) shows that, in general random directions and low intensities eliminate remnant magnetism as a significant factor in the analysis of anomalies considered by him. He finds granite of southeastern Missouri to have negligible remnant magnetism. Because of the general low intensities of remnant magnetism, it appears that it is also of no measurable significance in the present work.

SUMMARY OF COMPUTER PROGRAM

Originally, the author attempted to utilize a computer program prepared by Saad on the Royal McBee LGP-30 electronic digital computer of the University of Missouri at Rolla. However, the larger number of vertical dipoles required for actual geologic examples could not be accomodated by the program as prepared for the LGP-30 computer. Instead it became necessary to prepare a program for the IBM 1620 computer of the University of Missouri at Rolla which could readily handle the much larger number of computations required and at a higher rate of speed.

The object program and object deck, written in Fortran II language, is on file at the Computer Center of the University of Missouri at Rolla. Computer time required for a single point in a plane above a buried hill is four minutes and fifty seconds for the 540 vertical dipoles of the geologic model of Czar Knob. If fewer dipoles are used, computer time is reduced proportionately.

The routine to be followed in running the program is relatively simple. The object program deck is loaded into the IBM 1620 computer, followed directly by punched cards containing constants of the program.

The first card following the object deck is illustrated in Figure 70. The field of this data card is divided into seven columns, and values within each column are right-justified. The first number (18) at the left of the card, indicates the number of vertical dipoles of the buried hill model in a single row in the x (north) direction from the origin. The second number (30) indicates the number of vertical dipoles of the buried hill model in the y (east) direction. These

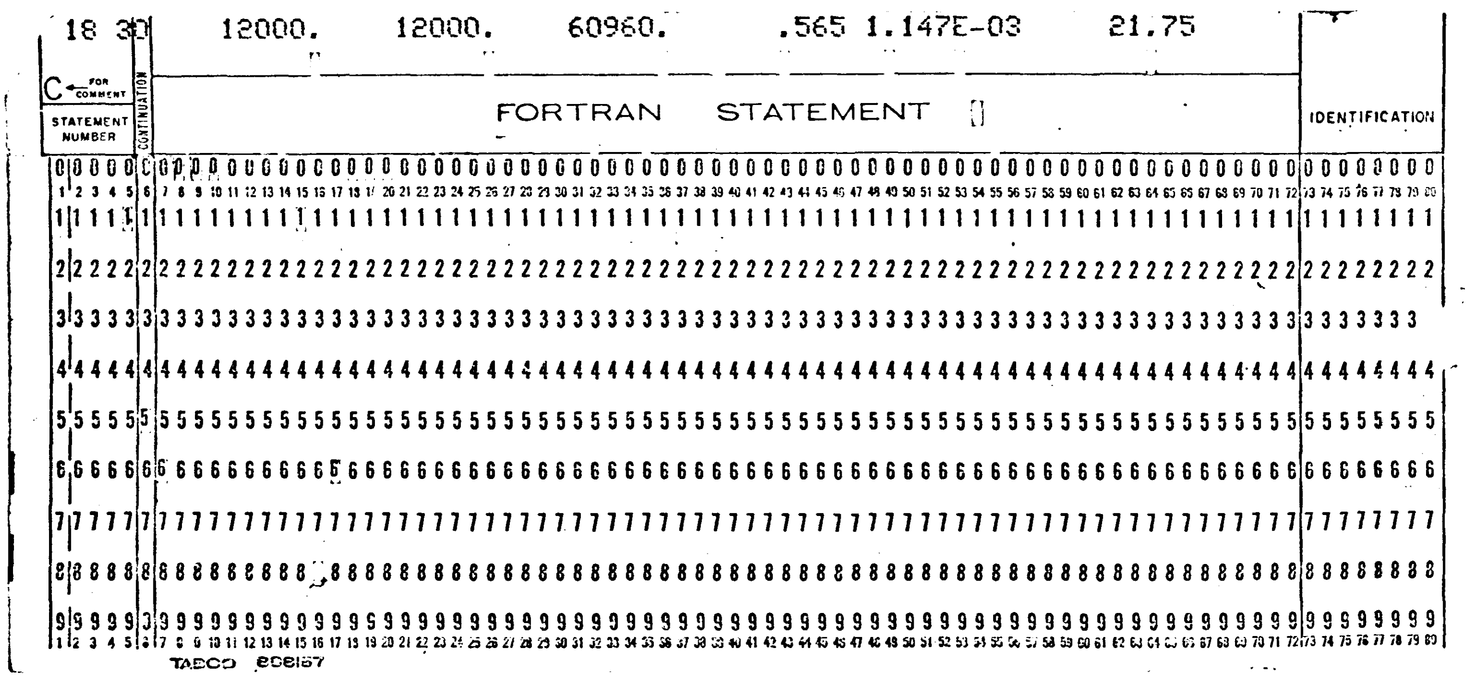


FIGURE 70. BASIC DATA CARD. SEE TEXT FOR EXPLANATION.

numbers allocate positions in storage for constants on subsequent cards.

The third and fourth numbers (12000., 12000.) are the cross-sectional dimensions in centimeters of a vertical dipole. Each vertical dipole must have the same cross-sectional dimensions, but may be either square or rectangular for a given geologic model. Square vertical dipoles are used in both the Czar Knob and Little Pilot Knob models.

The fifth number reading from the left (60960) is the distance in centimeters from the chosen horizontal plane downward to the base of all vertical dipoles. In the case of Czar Knob, the base of all vertical dipoles is sea level, and the elevation of the horizontal plane is 2,000 feet (60960 cm.) above sea level.

The sixth number from the left (.565) is the strength of the earth's total field in the area for which calculations are made. In the case of Czar Knob, this is 0.565 gauss, or 56,500 gammas (U. S. Coast and Geodetic Survey, 1955).

The seventh number from the left, (1.147E-03) is the magnetic susceptibility of the granite of Czar Knob (1.147×10^{-3} cgs units), as determined by the average of two measurements of a crushed sample of the granite.

The last number, (21.75) is the complement of the angle of inclination of the earth's total field in the area of Czar Knob. This angle 21° 45', is expressed in degrees and decimal part of a degree.

This data card is followed directly by data cards giving the vertical distance in centimeters from the assumed horizontal plane to the top of each vertical dipole of the buried hill model (Figure 71).

These data cards are divided into fields of seven columns, and values within each column are right-justified. The first value to be inserted on a card must be that for the extreme southwestern dipole of the buried hill model. Subsequently values for dipoles in this same row toward the east are inserted, until values for the entire bottom row are completed. Next, values for the second row from the bottom are inserted, again, beginning at the western side of the buried hill model, and reading eastward. This process is continued until values for all rows of vertical dipoles are inserted on data cards, and subsequently into memory locations in the computer.

Points in the horizontal plane above the buried hill are selected and punched on data cards, shown in Figure 72. Two fields of ten columns are utilized on each data card. The two figures, 72000 and 6000, are x and y coordinates in centimeters of a point lying in the horizontal plane above the buried hill. All values are measured in respect to the origin, located at the southwestern corner of the buried hill model. It is necessary to prepare a separate data card for each point in the horizontal plane, for which calculations are to be made.

When the program deck and the basic data cards have been loaded into the computer, actual computations can begin. The data cards as described in the paragraphs above, are placed in the reader hopper of the computer, where they are accepted, one at a time, as computation progresses.

As each additional data card is accepted by the computer, a card, as shown in Figure 73, containing results of computations for a preceeding point, is released. On this card are again listed the x and y coordinates

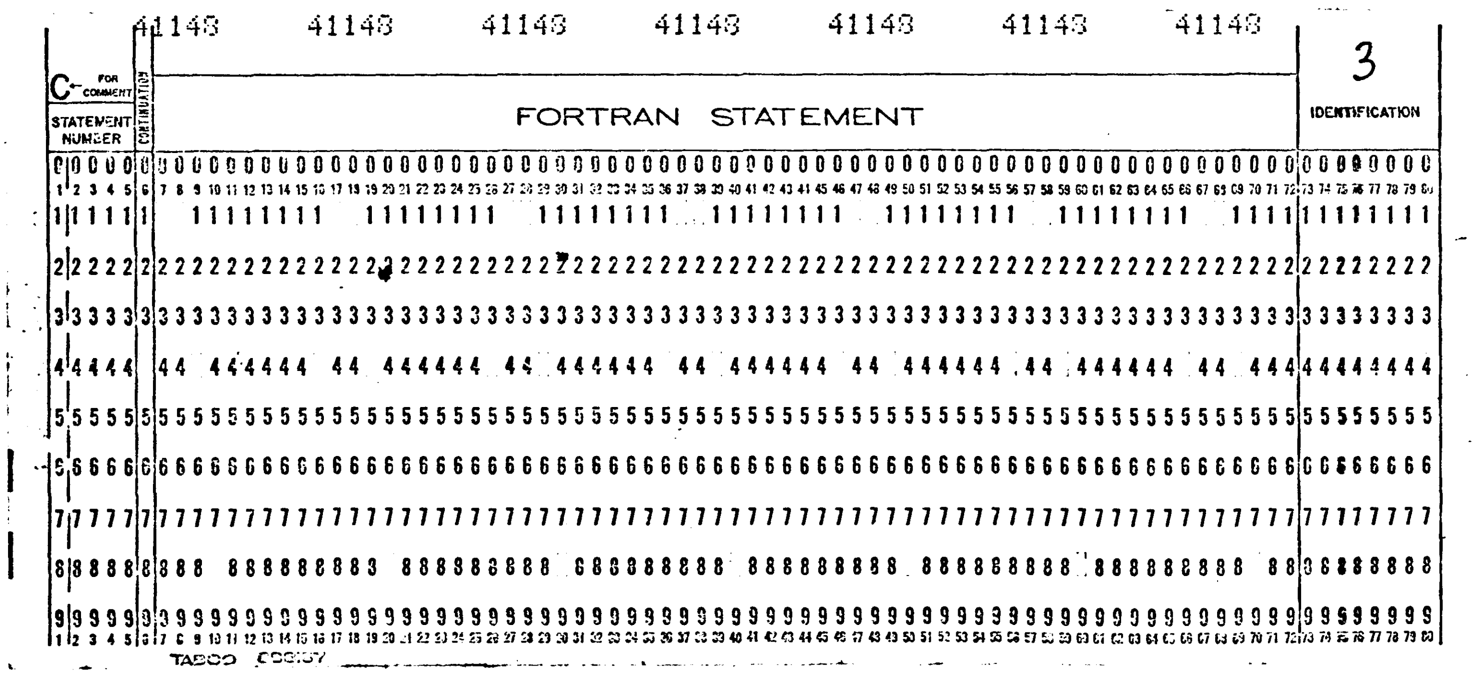


FIGURE 71. BASIC DATA CARD. SEE TEXT FOR EXPLANATION.

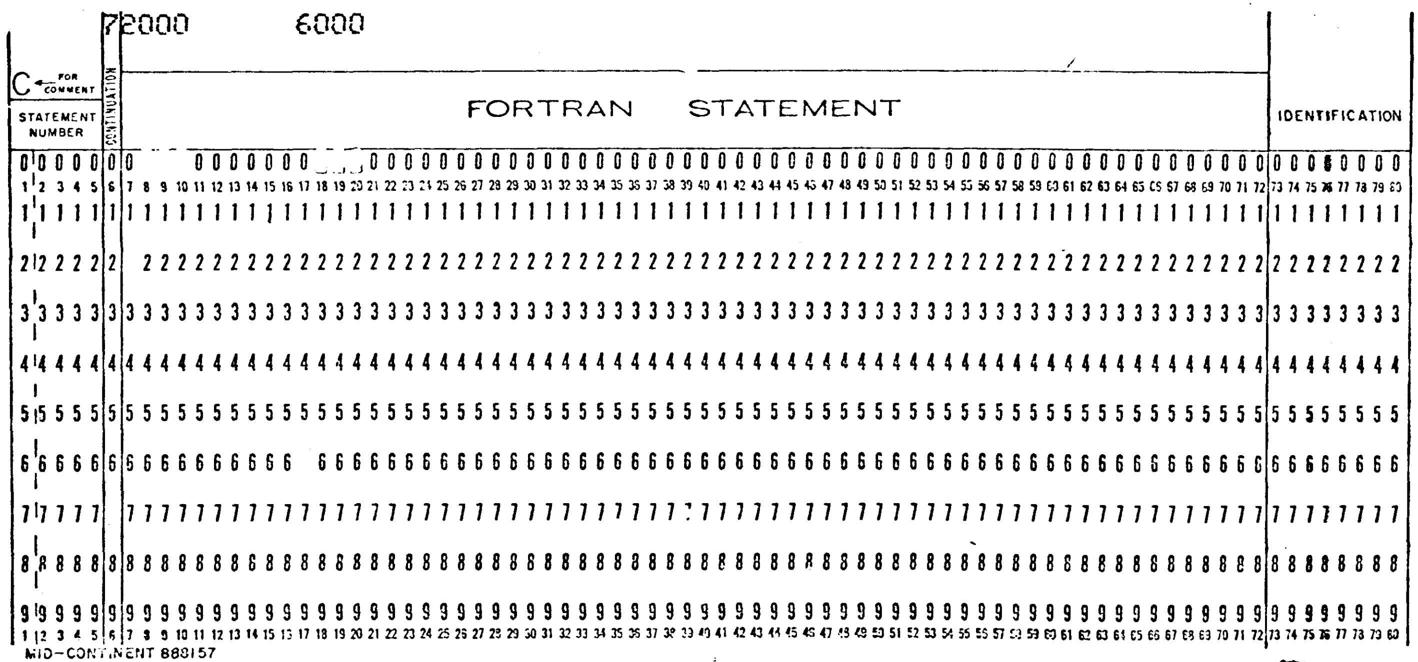


FIGURE 72. BASIC DATA CARD. SEE TEXT FOR EXPLANATION.

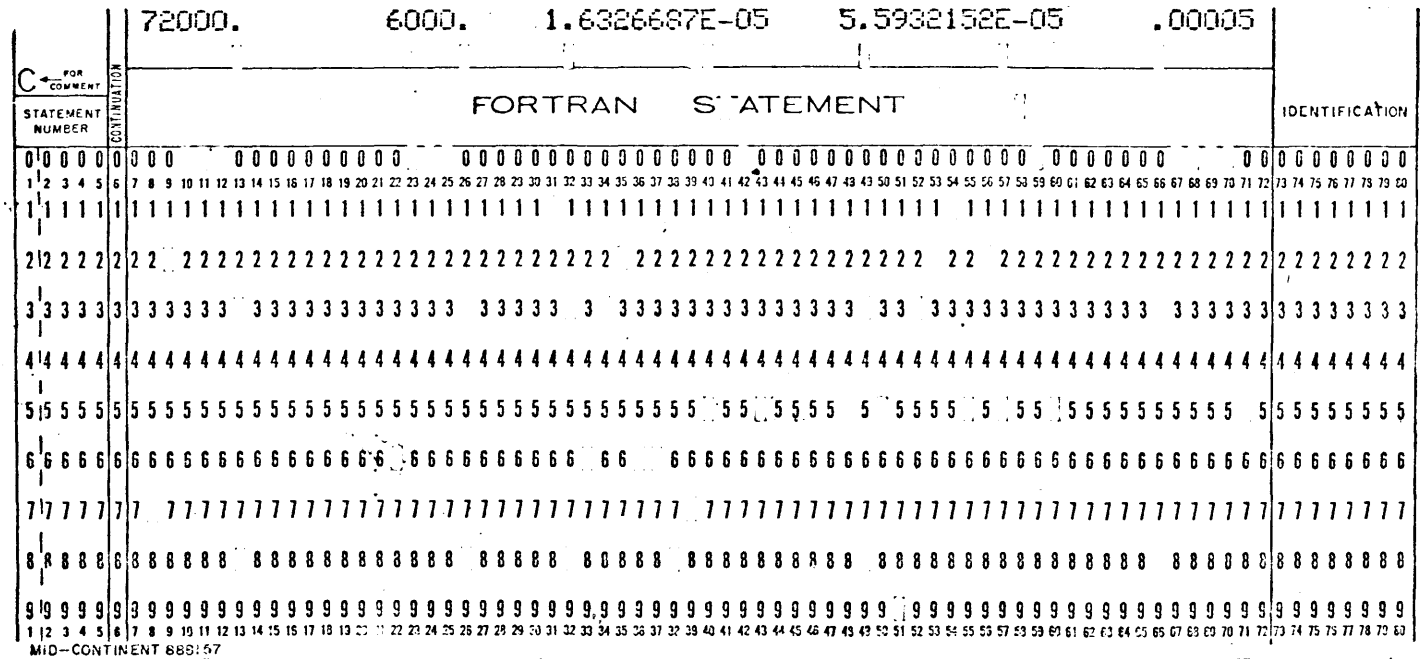


FIGURE 73. OUTPUT DATA CARD. SEE TEXT FOR EXPLANATION.

of the point for which computations are made (72000 and 6000). The third figure from the left is the value of horizontal intensity at the point listed (1.6326687E-05 or about 1.6 gammas). The fourth figure from the left is the value of vertical intensity for the point listed (5.5932152E-05 or about 5.6 gammas). The last figure from the left is the value of total intensity for the point listed (.0005 gauss or 5 gammas).

After a sufficient number of values have computed and plotted, contoured maps of horizontal intensity, vertical intensity, or total intensity may be prepared.

In the following two sections, total intensity magnetic maps are presented for Czar Knob and Little Pilot Knob, and the results are compared with actual aeromagnetic maps of the two areas.

COMPUTED TOTAL INTENSITY AEROMAGNETIC ANOMALY FOR CZAR KNOB

The geologic model used for computation of the magnetic anomaly associated with Czar Knob is shown in Figure 75. Contours on the Precambrian surface of Czar Knob are based upon outcrops drill hole data. The geologic model is divided into 540 vertical dipoles, each with its base at sea level. The elevation of tops of respective vertical dipoles in determined from the contoured map of the Precambrian surface. Other contents of the computation are also listed in Figure 75.

Description of the Computed Anomaly

Contoured values of total intensity for an elevation of 2,000 feet above sea level for the geologic model of Czar Knob are presented in

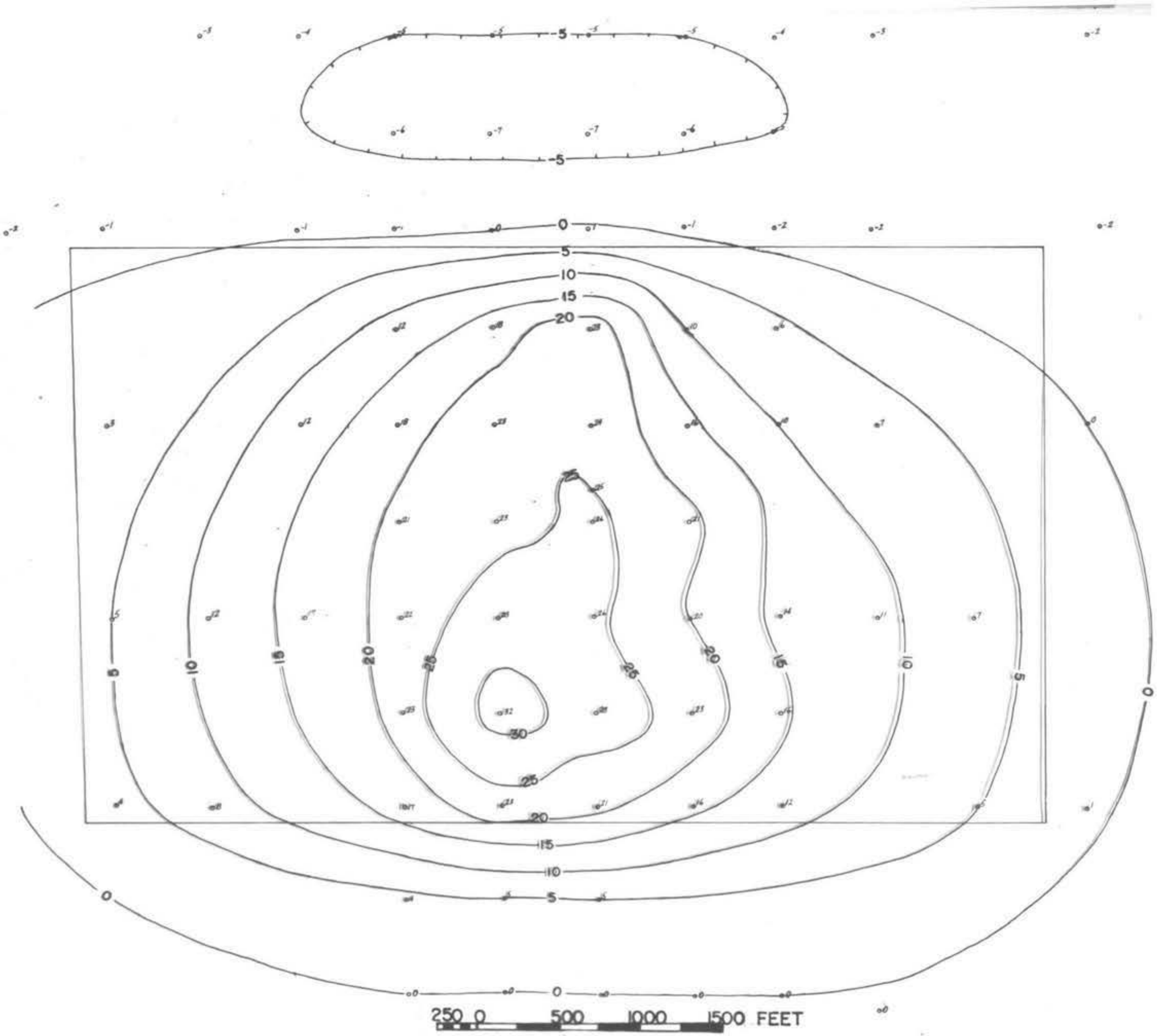
Figure 74 drawn at a scale of 1 inch equals 1,000 feet. The contours are based upon values computed for eighty points, requiring a total computation time of seven hours.

The amplitude of the computed anomaly (measured from lowest value to highest) is 39 gammas. The crest of the anomaly lies 2,600 feet south and slightly west of the crest of Czar Knob. An area of higher total intensity value extends northward from the crest of the anomaly to a point directly overlying the exposed summit of Czar Knob. The anomaly is broadly oval-shaped, measuring about three miles in an easterly direction, and about two and one-half miles in a northerly direction. A broad area of negative value of total intensity is present at the northern margin of the anomaly. The minimum negative value in this area is -7 gammas.

Comparison of the Computed Anomaly with the Total Intensity Aeromagnetic Map of Czar Knob

The total intensity aeromagnetic map of the Czar Knob area, at a height of 2,000 feet above sea level, is presented in Figure 19, at a scale of 1 inch equals 2,000 feet. While the scales of the two maps are different the aeromagnetic anomaly closely resembles the computed anomaly in its general east-west strike. The aeromagnetic anomaly has a magnitude of about 40 gammas, in comparison with 39 gammas for the computed anomaly.

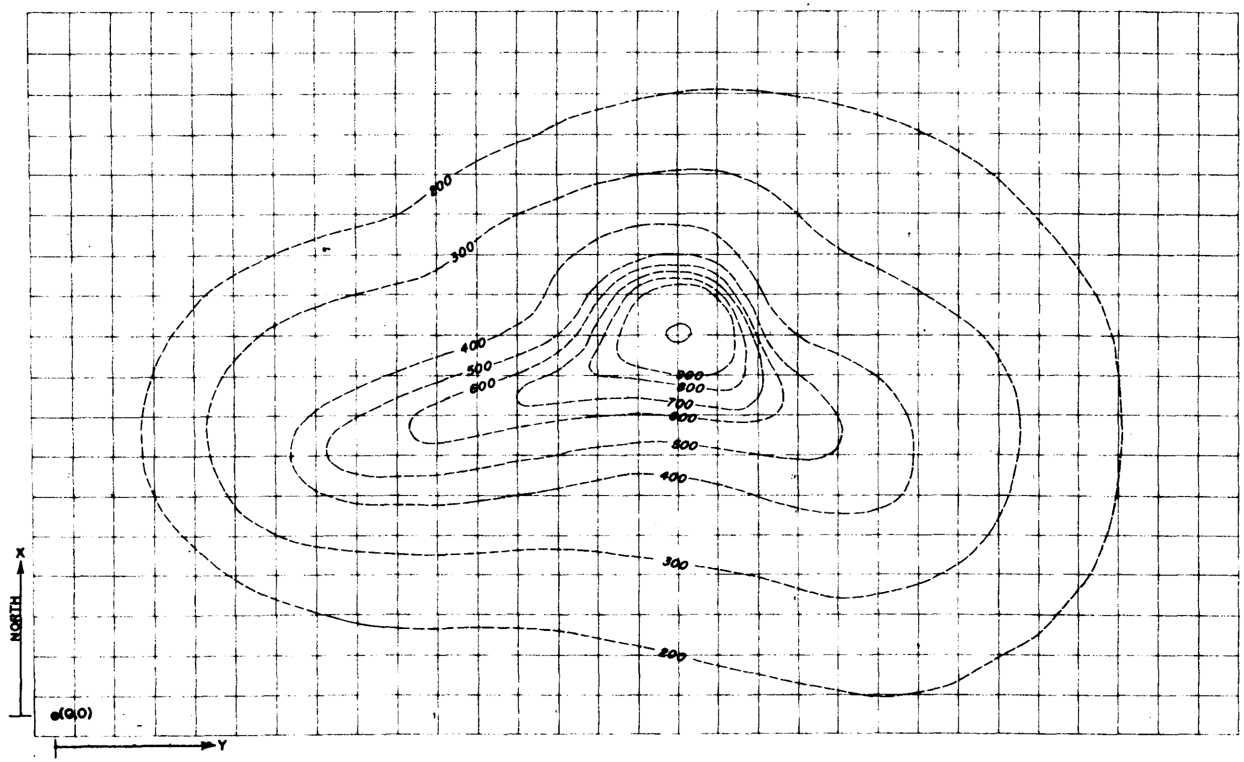
However, the aeromagnetic map reveals the presence of a closed anomaly about one mile to the east of the crest of the computed anomaly. Computations show that this closure is clearly is not produced by the geologic model for Czar Knob. These data strongly suggest the presence of a second totally buried Precambrian hill about one mile east of Czar



COMPUTED TOTAL INTENSITY AEROMAGNETIC ANOMALY FOR CZAR KNOB

CONTOUR INTERVAL 5 GAMMAS

FIGURE 74



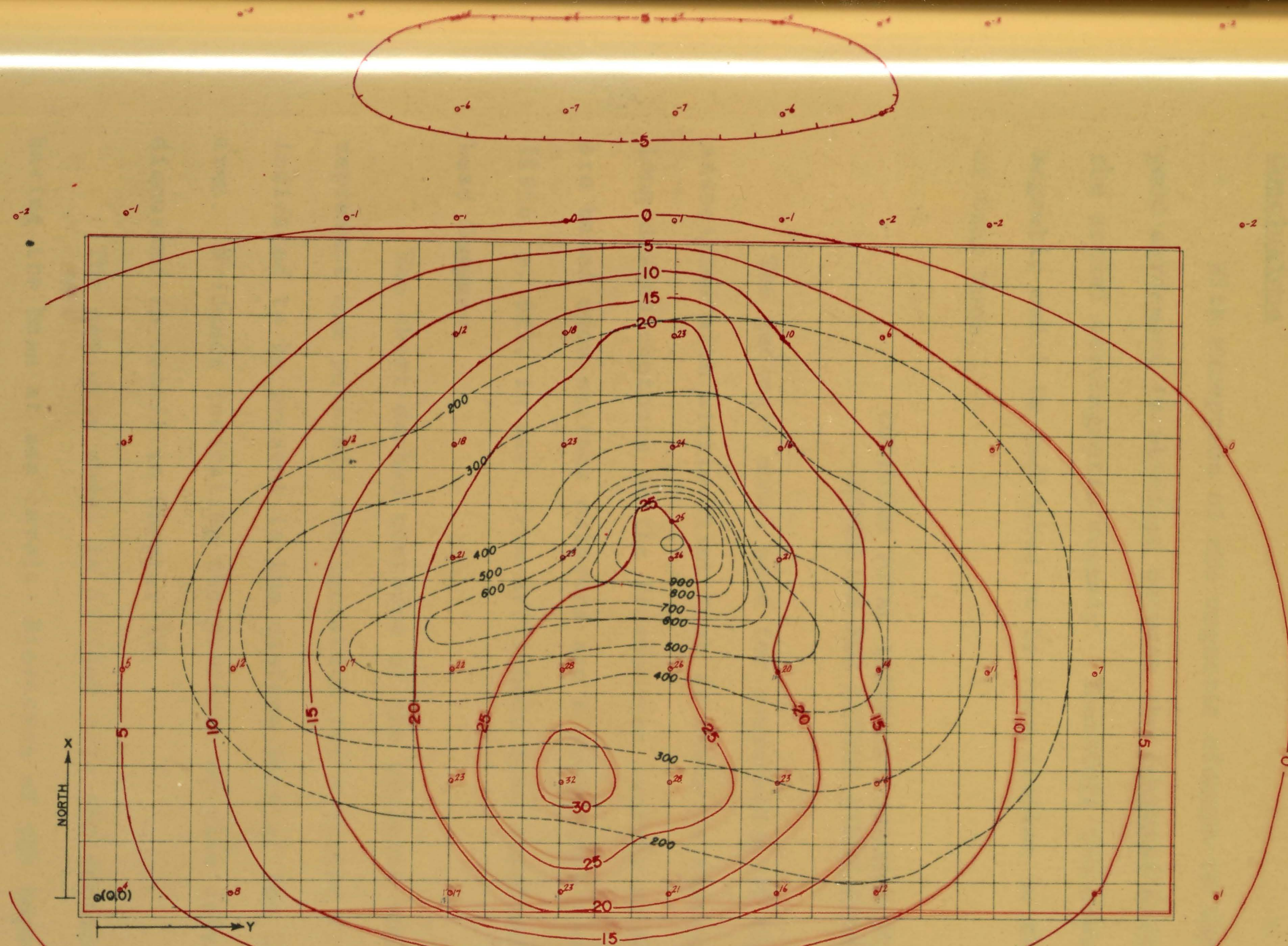
GEOLOGIC AND MAGNETIC MODEL OF CZAR KNOB

SPECIFICATIONS

1. VERTICAL DIPOLES: 6000 x 6000 cm.
2. BASE OF ALL DIPOLES: SEA LEVEL
3. TOP OF INDIVIDUAL DIPOLES: CORRESPONDS WITH ELEVATION OF PRECAMBRIAN SURFACE, AS INDICATED BY STRUCTURE CONTOURS
4. ELEVATION FOR TOTAL INTENSITY CALCULATIONS: 2000 ft. ABOVE SEA LEVEL
5. STRENGTH OF EARTH'S TOTAL FIELD AT CZAR KNOB: .565 GAUSS
6. MAGNETIC SUSCEPTIBILITY OF CZAR KNOB GRANITE: 1.147×10^{-3} CGS UNITS
7. ANGLE OF INCLINATION OF EARTH'S TOTAL FIELD AT CZAR KNOB: 68°15'

250 0 250 500 750 1000 1250 1500 FEET

FIGURE 75



GEOLOGIC AND MAGNETIC MODEL OF CZAR KNOB

SPECIFICATIONS

1. VERTICAL DIPOLES: 6000 x 6000 cm.
2. BASE OF ALL DIPOLES: SEA LEVEL
3. TOP OF INDIVIDUAL DIPOLES: CORRESPONDS WITH ELEVATION OF PRECAMBRIAN SURFACE, AS INDICATED BY STRUCTURE CONTOURS
4. ELEVATION FOR TOTAL INTENSITY CALCULATIONS: 2000 ft. ABOVE SEA LEVEL
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6. MAGNETIC SUSCEPTIBILITY OF CZAR KNOB GRANITE: 1.147×10^{-3} CGS UNITS
7. ANGLE OF INCLINATION OF EARTH'S TOTAL FIELD AT CZAR KNOB: 68°15'

250 0 250 500 750 1000 1250 1500 FEET

FIGURE 75

250 0 500 1000 1500 FEET

COMPUTED TOTAL INTENSITY AEROMAGNETIC ANOMALY FOR CZAR KNOB

CONTOUR INTERVAL 5 GAMMAS

FIGURE 74

Knob, and lying along the trend of Czar Knob. No drill hole data are presently available to confirm the presence of this inferred buried hill.

Conclusions

With exception of the magnetic closure to the east of Czar Knob, good agreement is obtained between the computed anomaly for Czar Knob and the actual aeromagnetic anomaly. Therefore the assumed geologic and magnetic model is indicated to be very similar to the actual buried hill of Czar Knob.

COMPUTED TOTAL INTENSITY AEROMAGNETIC ANOMALIES FOR LITTLE PILOT KNOB

The geologic model used for computation of the magnetic anomalies associated with Little Pilot Knob is shown in Figure 77. Solid and long-dashed contours in the Precambrian surface of Little Pilot Knob are based upon surface outcrops and a subsurface map prepared by French (1956, p. 62), in part from drill-hole data supplied by the St. Joseph Lead Company.

The short-dashed contours of the geologic model are inferred, and represent one possible configuration for a buried Precambrian hill indicated to be present in the eastern part of the Little Pilot Knob area. Evidence indicating the presence of this inferred buried hill is discussed in detail in Chapter IV.

The geologic model is divided into 552 vertical dipoles, each having its base at sea level. Elevation of the tops of respective vertical dipoles is determined from the contour map of the Precambrian surface.

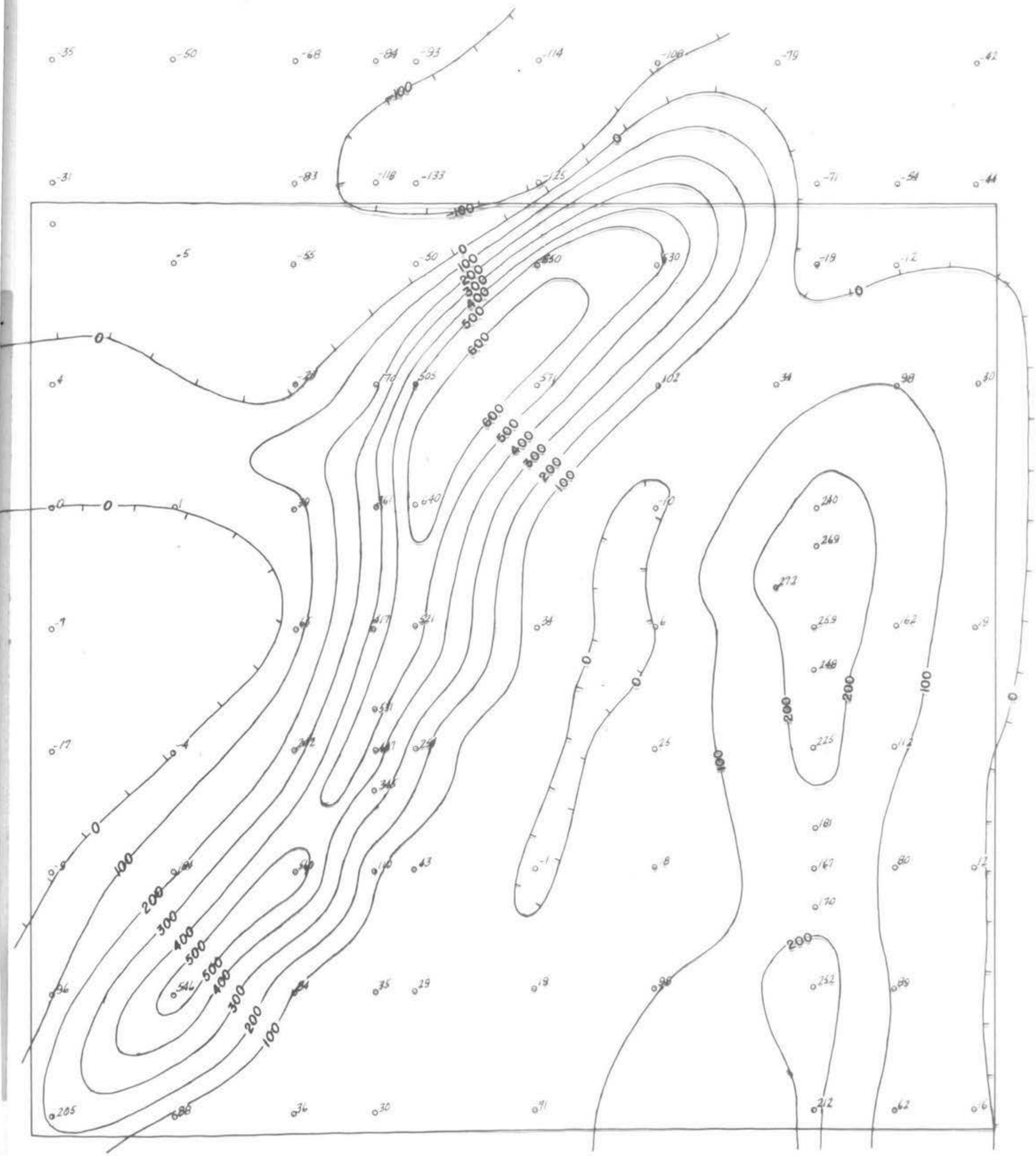
Other constants of the computation are listed in Figure 77.

Description of the Computed Anomalies

Contoured values of total intensity for an elevation of 1,800 feet above sea level for the geologic model of Czar Knob are shown in Figure 76. The contours are based upon values computed for ninety eight points, requiring a total computation time of approximately eight hours. Amplitude of the computed anomaly (measured from lowest value to the highest) is about 773 gammas. The point of maximum value of total intensity is immediately east of the northern tip of exposed trachyte porphyry of Little Pilot Knob. Here, a computed total intensity value of 640 gammas is obtained. The minimum value of computed total intensity lies about 4,500 feet due north of the maximum value described above, in an area of negative total intensity values. Here, the computed total intensity value is -133 gammas.

A striking feature of the computed total intensity map is an elongate anomaly extending generally northeastward and lying slightly to the south of the exposed trachyte porphyry ridge. Values along the crest of this elongate anomaly range from 500 gammas to the maximum described above of 640 gammas. This anomaly is clearly related to the exposed trachyte porphyry ridge.

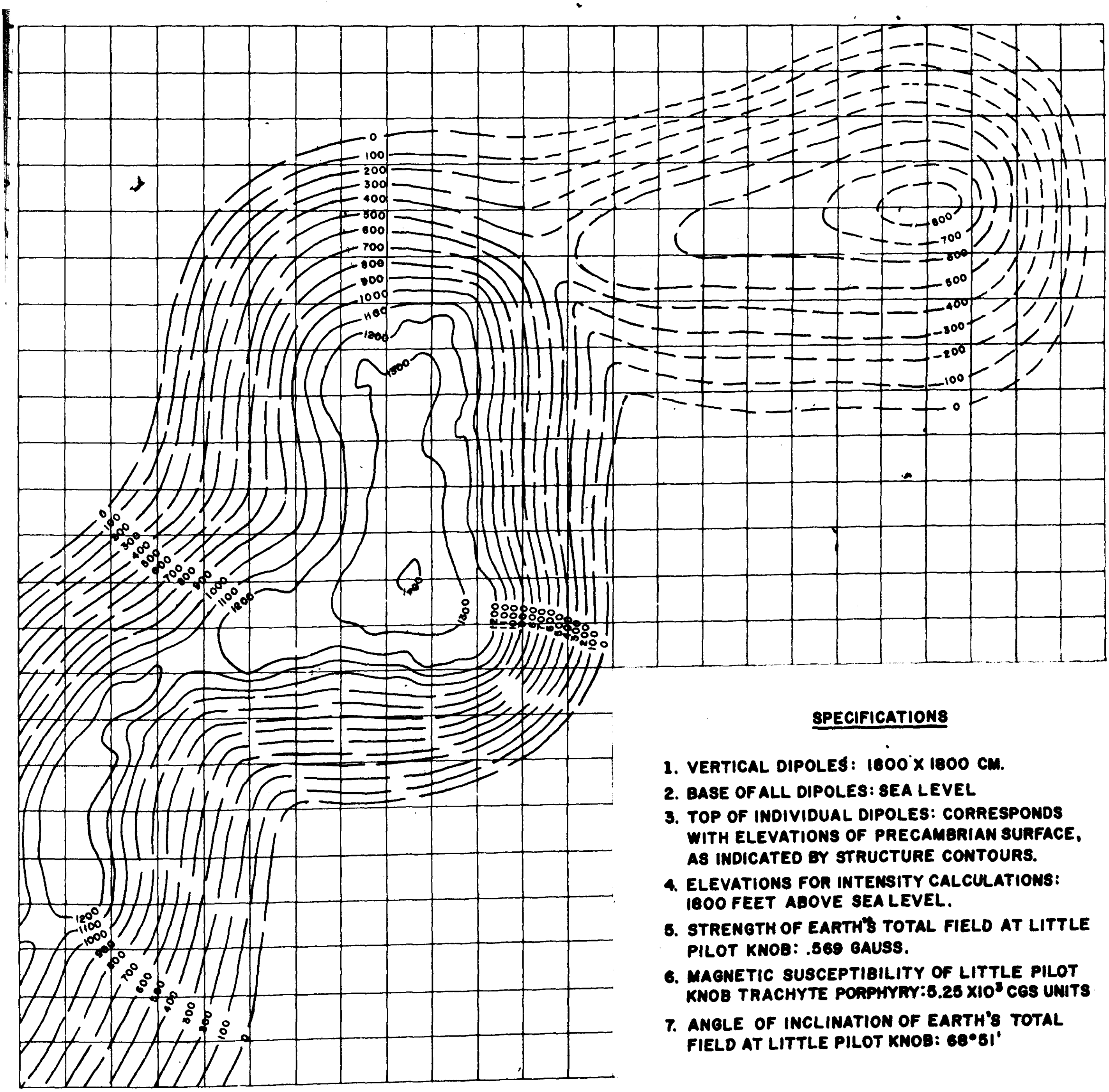
A second elongate anomaly lies near the eastern margin of the area. Values of computed total intensity ranging to a maximum of 272 gammas lie along the crest of this anomaly. The northern portion of this anomaly is located about 2,500 feet south of the crest of the inferred buried hill described above, and appears to be related to it.



COMPUTED TOTAL INTENSITY AEROMAGNETIC MAP OF LITTLE PILOT KNOB AREA

CONTOUR INTERVAL 100 GAMMAS

FIGURE 76



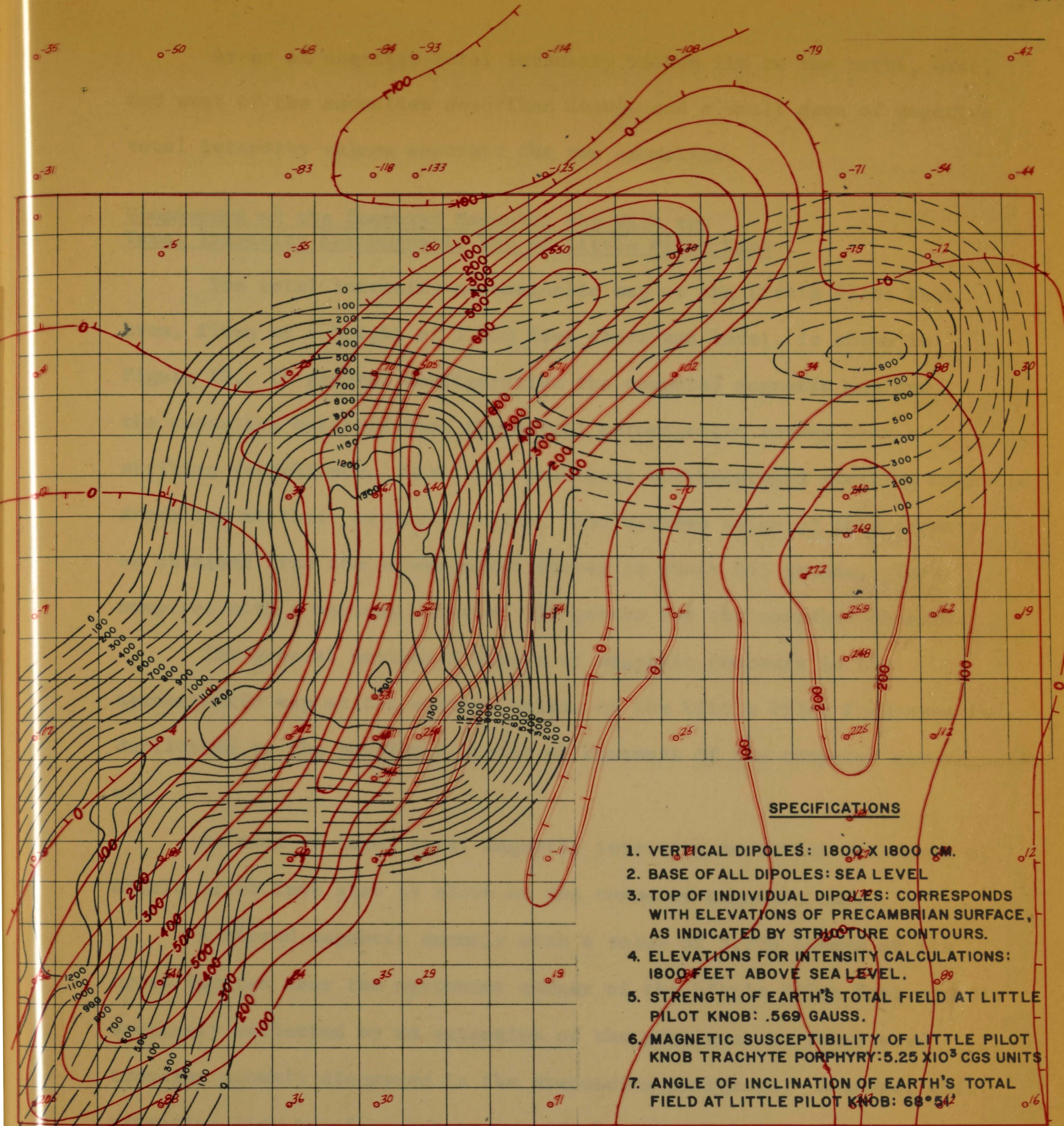
SPECIFICATIONS

1. VERTICAL DIPOLES: 1800 X 1800 CM.
2. BASE OF ALL DIPOLES: SEA LEVEL
3. TOP OF INDIVIDUAL DIPOLES: CORRESPONDS WITH ELEVATIONS OF PRECAMBRIAN SURFACE, AS INDICATED BY STRUCTURE CONTOURS.
4. ELEVATIONS FOR INTENSITY CALCULATIONS: 1800 FEET ABOVE SEA LEVEL.
5. STRENGTH OF EARTH'S TOTAL FIELD AT LITTLE PILOT KNOB: .569 GAUSS.
6. MAGNETIC SUSCEPTIBILITY OF LITTLE PILOT KNOB TRACHYTE PORPHYRY: 5.25 X10^{3} CGS UNITS
7. ANGLE OF INCLINATION OF EARTH'S TOTAL FIELD AT LITTLE PILOT KNOB: 68°51'

GEOLOGIC AND MAGNETIC MODEL OF LITTLE PILOT KNOB

500 0 1000 2000 3000 FEET

FIGURE 77



GEOLOGIC AND MAGNETIC MODEL OF LITTLE PILOT KNOB

COMPUTED TOTAL INTENSITY AEROMAGNETIC MAP OF LITTLE PILOT KNOB AREA

500 0 1000 2000 3000 FEET

FIGURE 77

CONTOUR INTERVAL 100 GAMMAS

FIGURE 76

Areas of negative total intensity values lie to the north, east, and west of the anomalies described above, and a small area of negative total intensity values separate the two anomalies.

Comparison of the Computed Magnetic Map With the Total Intensity Aeromagnetic Map of Little Pilot Knob

The total intensity aeromagnetic map of the Little Pilot Knob area, flown at a height of 1,800 feet above sea level, is shown in Figure 12. In general configuration the computed magnetic map and the anomalies obtained from the actual aeromagnetic survey bear a striking resemblance. Both have prominent northeastward striking magnetic anomalies at their western margins. The maximum value of this anomaly as obtained from the aeromagnetic survey is about 955 gammas. This compares with a maximum value of 773 gammas for the computed anomaly.

The general northward strike of magnetic contours in the aeromagnetic map at the eastern margin of the Little Pilot Knob area is duplicated by the northward strike of contours of the computed aeromagnetic map.

An area of lower total magnetic intensity northwest and north of Little Pilot Knob also is shown on the computed magnetic map.

A closed magnetic anomaly with a value of 3,220 gammas at its crest located near the northwest corner of the Little Pilot Knob area is seemingly reflected by an extension of the prominent northwestward trending anomaly discussed in the preceeding paragraph. However, this extension lies too far west to provide a good match for the actual closed aeromagnetic anomaly.

Conclusions

The computed aeromagnetic map for the Little Pilot Knob area shows a close correspondence to the actual aeromagnetic map of the area. A significant difference between the two maps is the absence of a large closed anomaly near the northeast corner of the computed aeromagnetic map. This difference suggests the assumed geologic model for the buried hill in the northeast part of the area is not well matched with the actual buried hill.

The geologic model for this buried hill, as shown in Figure 77, is connected to the exposed trachyte porphyry of Little Pilot Knob. This connection to Little Pilot Knob probably does not exist on the actual buried Precambrian Hill. Instead, a fairly pronounced depression probably lies between Little Pilot Knob and the buried Precambrian hill. Also the buried hill probably extends farther to the east, and slightly farther north than shown in Figure 77. If the geologic model were thus revised, it is believed that a much closer match to the actual anomaly might be obtained.

A difference in amplitude of about 200 gammas is noted between the elongate aeromagnetic anomaly in the western part of the area, and the computed anomaly. Because the computed anomaly is about 200 gammas low, the writer suspects that the samples of Little Pilot Knob trachyte porphyry used for determination of magnetic susceptibility may have been slightly weathered. These samples were taken from the center of a boulder found near the crest of Little Pilot Knob and appeared entirely unweathered.

ORIGIN OF JOINTS ADJACENT TO PRECAMBRIAN HILLS

Joints were mapped in sedimentary rocks in five of the six buried hill areas covered in this report. In three of these areas they were also mapped within the Precambrian igneous rocks. In the sedimentary rock section they are vertical or nearly vertical, while those observed in the igneous rocks are vertical and at various other angles. Little, if any, relationship appears to exist between the fractures of the igneous exposures, and those present in the overlying sedimentary rocks.

In the five sedimentary rock areas most of the vertical joints strike parallel to the outline of the exposed Precambrian hill or knob. This relationship is well shown at Czar Knob and Eminence Knob (Figure 28 and 53). A similar relationship seems fairly well established in the Taum Sauk and Caledonia areas. It is less well shown at Little Pilot Knob (Figure 18). The strike of joints at Little Pilot Knob may, however, be influenced by faulting.

James (1952) reports similar fracture relationships adjacent to Precambrian hills in the underground workings in mining areas. He indicates the fractures parallel the gross configuration of the knobs, and suggests they are important in the localization of lead deposits.

In the following chapter, evidence is presented to show that compaction of original lime muds by as much as 25 percent is likely. This compaction is the result of loss of water contained in the lime mud, and a general crystallization and interlocking of component carbonate particles. The effect of a 25 percent compaction upon sediments adjacent to a Precambrian hill is shown in Figure 78. The

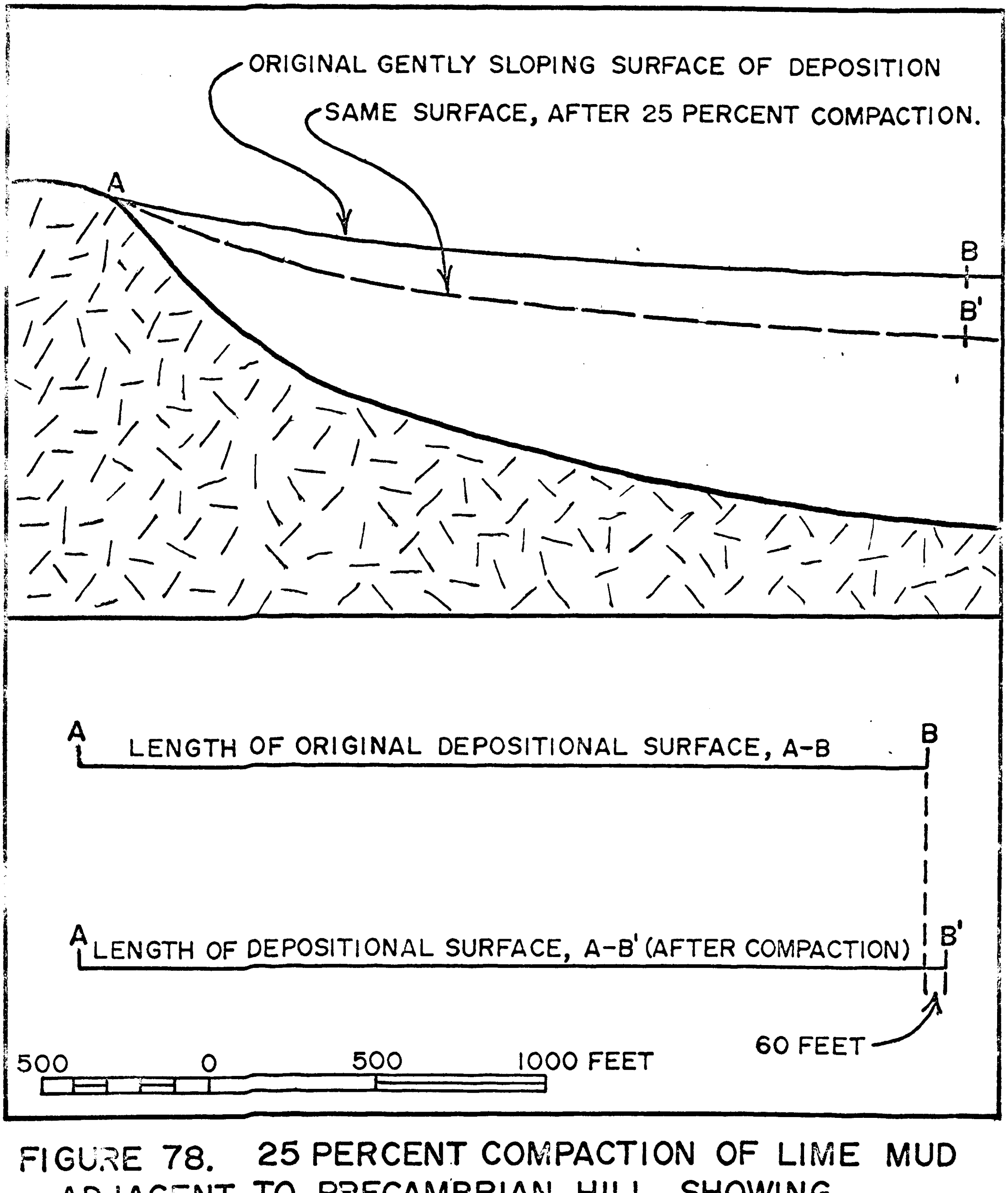


FIGURE 78. 25 PERCENT COMPACTION OF LIME MUD ADJACENT TO PRECAMBRIAN HILL, SHOWING RESULTANT INCREASE IN LENGTH OF DEPOSITIONAL SURFACE BY 60 FEET OR 2-1/2 PERCENT.

gently sloping original surface of deposition is A-B. The same depositional surface is shown, after compaction of the sediments by 25 percent, at A-B'. The length of the original depositional surface before compaction is shown in the lower part of Figure 78, by straight line A-B. The length of the depositional surface after compaction is shown by straight line, A-B'. This surface has been lengthened by about 60 feet during compaction or by about 2½ percent. One of the results of this would be to produce significant tensional stresses, away from the Precambrian hill, and toward the areas where the greatest amount of compaction would be expected.

Experimental Analysis of Tension Fractures

Ernst Cloos (1955) considers the effects of tensional forces in soft clay. He uses a two inch thickness of clay, placed on a movable square of wire cloth. Tensional stress is introduced by pulling on opposite corners of the wire cloth. Cloos reports that prominent tension fractures developed in the soft clay if the surface was liberally sprinkled with water. The experimental setup of Cloos, with tensional stresses shown, and resultant tension fractures, is illustrated in Figure 79.

V. V. Belousov (1961) describes results of his experiments with deformation of clay at the Institute of Physics of the Earth at the U.S.S.R. Academy of Sciences in Moscow. He shows the development of both longitudinal and cross fractures of tensional origin in soft clay when a cylinder is slowly forced upward through the clay. The longitudinal fractures develop parallel to the long axis of the horizontal cylinder, while cross fractures form perpendicular to the long axis.

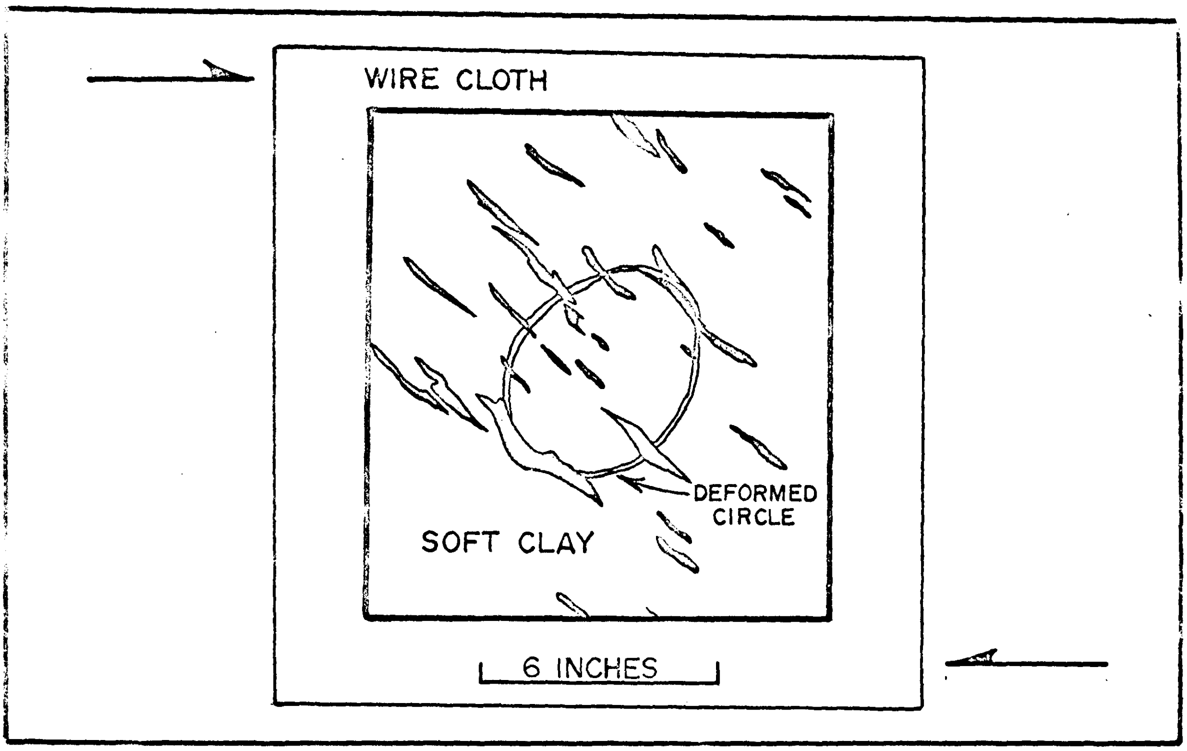


FIGURE 79. TENSION FRACTURE DEVELOPMENT IN SOFT CLAY, WITH STRESS DIRECTIONS SHOWN BY ARROWS. (AFTER E. CLOOS, 1955, PLATE I, FIGURE I)

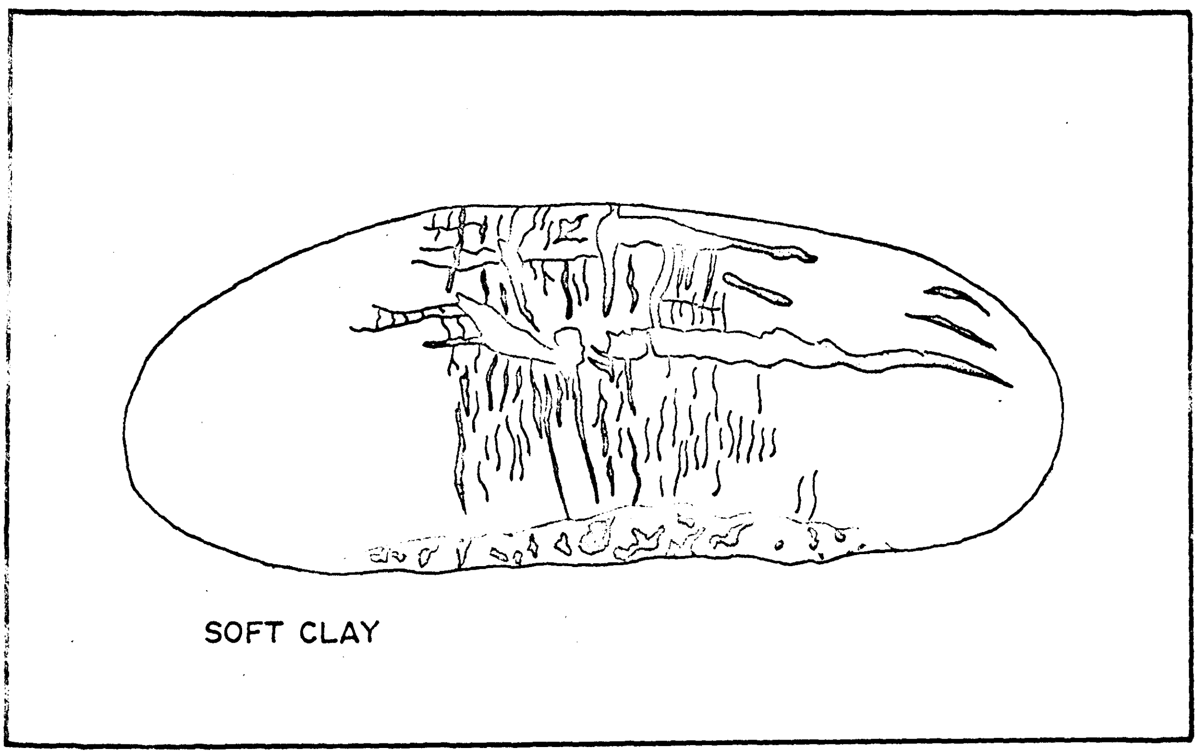


FIGURE 80. TENSION FRACTURES ON SMALL ELLIPTICAL MOUND, FORMED WHEN A PISTON IS SLOWLY MOVED UPWARD THROUGH SOFT CLAY. (AFTER BELOUSOV, 1961, P. 102)

The fractures in soft clay that resulted from this experiment are shown in Figure 80. An analogy can be drawn between conditions of this experiment and geologic conditions that are believed to have existed in nearly saturated and slowly compacting lime muds adjacent to Precambrian hills. In the Belousov experiment the cylinder moved upward relative to the adjacent soft clay. In the case of the Precambrian hills, the compacting sediments move downward in relation to the rigid Precambrian core. The relative movement is the same in each case. The results of both the laboratory experiment and field observations show rather good correspondence.

Theoretical Analysis

As noted, tensional stresses are believed to have developed in compacting sediments adjacent to Precambrian hills. Theoretical results of such stresses can be predicted by strain ellipsoid analysis of the stress environment. In Case I (Figure 81) a simplified version of the problem is shown. The sediments are assumed to be homogeneous lime mud. Under the conditions illustrated a simple couple would exist. Tension fractures should strike parallel to the flanks of the knob, and dip at a fairly high angle away from the knob (A-A' Figure 81). Shear fractures would also parallel the flanks of the knob, and would develop at a very high angle toward the knob (B-B') and at a very low angle toward the knob (C-C'), or if enough movement occurred, essentially parallel to the bedding planes. However, Cloos (1955) reports shear fractures developed very slowly in his experimental model, and only if the clay surface was relatively free of moisture.

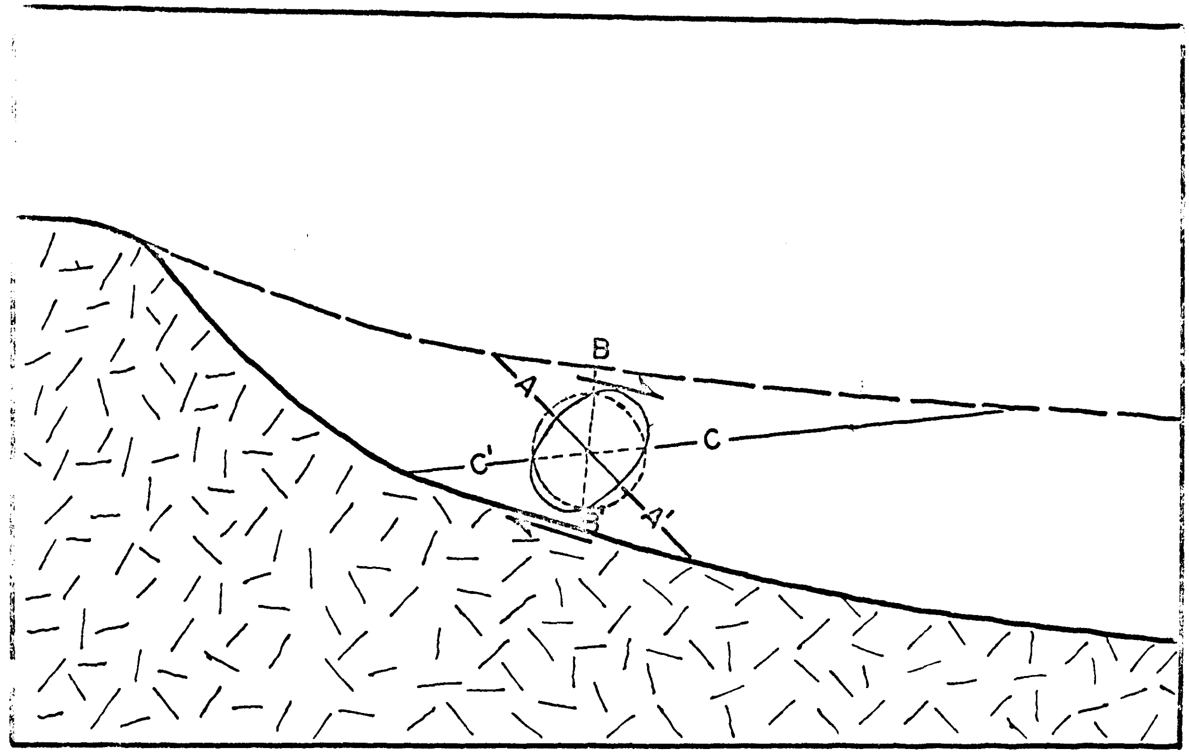


FIGURE 81. CASE I. MOVEMENT IS ASSUMED TO BE EQUAL THROUGHOUT THE VERTICAL SECTION OF SEDIMENTS. TENSION FRACTURE IS AT A-A', AND SHEAR FRACTURES ARE AT B-B' AND C-C'.

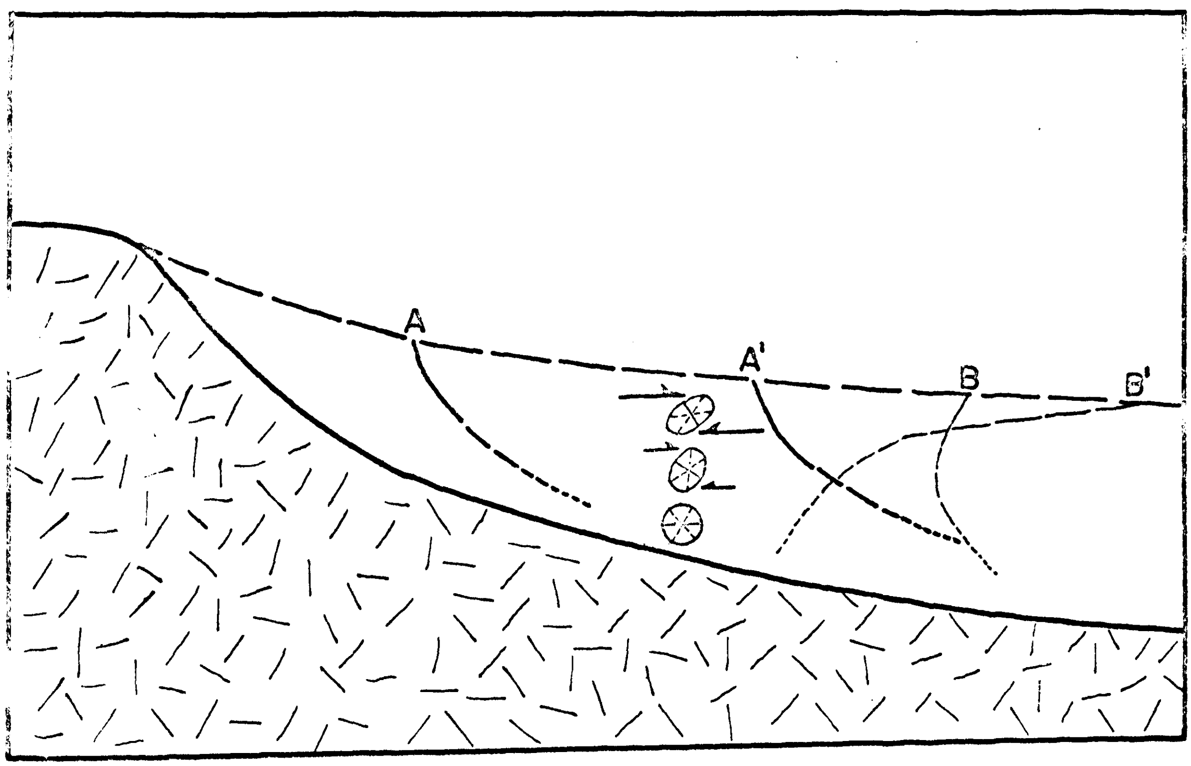


FIGURE 82. CASE II. MOVEMENT DECREASES WITH DEPTH. A SERIES OF STRAIN ELLIPSOIDS SUGGEST A GRADUAL CHANGE IN TENSIONAL AND SHEAR FRACTURE ANGLES, FROM STEEP NEAR THE SURFACE, TO MORE GENTLE AT DEPTH. TENSION FRACTURES ARE AT A, AND A'; SHEAR FRACTURES AT B, AND B'.

Case II is illustrated in Figure 82. Here the rotational stress decreases with increasing depth, and the amount of deformation is less, as indicated by the orientation of the strain ellipsoids. The ultimate effect is the change in the angle of inclination of the tensional and shear fractures. At a position of minimal rotation, the original circle is hardly deformed and the fractures would not be expected to develop from the above stress environment. One should expect, therefore, the tensional joints to be steeper at the surface, become less inclined with depth, and finally die out in the zone of non-rotational movement.

A complicating factor would be the vertical component of compaction in the lower zone. This may have a horizontal component of motion when the sediments were on a moderately or steeply inclined Precambrian depositional surface.

Further factors in the above analysis are the presence of bedding planes in the sediments, variations in the nature of the sediments, and the gradual decrease in moisture content with increasing depth. The combined effects of these factors might well influence the attitude and dominance of the type of fractures formed.

Experimental and Theoretical Data and Field Observations

The foregoing data suggest a complicated pattern of both tension and shear fractures should be present in sedimentary rocks adjacent to Precambrian hills. Experimental and theoretical analysis suggests the fractures should parallel the flanks of the Precambrian hills. Field observations in five of the six study areas confirm these general predictions.

Experimental and theoretical considerations suggest the fractures should be inclined from nearly vertical to gently dipping. Nearly all joints observed in this study appear to be essentially vertical. However, field observations were limited largely to the trace of the fractures. While it was relatively simple to measure strikes, it was more difficult to make an accurate measurement of the angle of dip. If more precise measurements of the angle of dip of joints were available, they might prove to be more in accord with theoretical considerations.

Unknown factors, some of which are noted in an earlier paragraph, are the presence of bedding planes, variation in the nature of the sediments, variation in moisture content with depth, angle of slope of the underlying Precambrian surface and amount of compaction. The combined influence of these factors are not evaluated, but might be expected to produce some deviations in joint patterns from the simplified theoretical analysis.

Conclusions

In consideration of the foregoing evidence, it appears likely that the joints mapped in sedimentary rocks adjacent to Precambrian hills in the areas of this report are produced by tensional or shear stresses that arose while the sediments were undergoing compaction. Comparison of experimental and theoretical fracture patterns with those observed in the field indicates a fair to good correspondence. The somewhat more complicated pattern of the theoretical analysis, might be even more closely resolved with field observations, if all variable factors could be included in the theoretical analysis, and more complete and detailed exposures of the joints were available in the field.

GENERAL CONCLUSIONS

ORIGIN OF PERIPHERAL DIPS

Peripheral dips are observed in sedimentary rocks adjacent to buried or resurrected Precambrian hills in all areas studied in this report, with the exception of the Sullivan area. A maximum value for peripheral dips of 34 degrees was observed in sedimentary rocks immediately adjacent to rhyolite porphyry in the Eminence area. Rocks showing dips exceeding 20 degrees were observed in three areas. Peripheral dips of more than 10 degrees were observed in five of the six areas. The rocks showing peripheral dips strike essentially parallel to the exposed outline of a knob, and dip away from the knob.

Dake and Bridge (1932) have considered the problem of origin of peripheral dips in detail. In their works they consider the dips to be largely those that existed on depositional surfaces at the time of deposition. They term these "initial dips." While they believe compaction may have steepened these dips somewhat, they feel it has played only a minor role.

This concept of "initial dip" is re-evaluated in the following paragraphs, in light of observations made during this study, and in consideration of data pertinent to this subject in more recent publications.

Physical Characteristics of Peripheral Dips

Peripheral dips observed during this study have one outstanding characteristic in common. The dips are very steep immediately adjacent to the Precambrian hill, but decrease to about half their maximum values within a very short distance from the exposed hill, usually within less than 200 feet. The dips then continue to decrease at a slower rate to about 400 feet from the Precambrian exposure.

At distances greater than 400 feet from the Precambrian hills, peripheral dips are very low, almost invariably less than 10 degrees and usually much less. At distances greater than 1,000 feet from the Precambrian hills, nearly flat-lying rocks are observed.

Thus, steeper peripheral dips are localized, usually in an area less than 1/5 mile in width, adjacent to buried hills.

A second characteristic the observed peripheral dips have in common is the "hinge line" separating the zone of high dips immediately adjacent to a Precambrian hill from the zone where peripheral dip are considerably lower. This "hinge line" is well illustrated in Figure 83, an overlay of the Taum Sauk Cut showing only bedding planes. This "hinge line" also can be identified in Figures 27, 49, and 52, graphs showing decrease in rate of dip for Czar Knob, the Taum Sauk area, and Eminence area. Whatever explanation is offered for the origin of peripheral dip, must also explain the origin of this "hinge line" phenomenon.

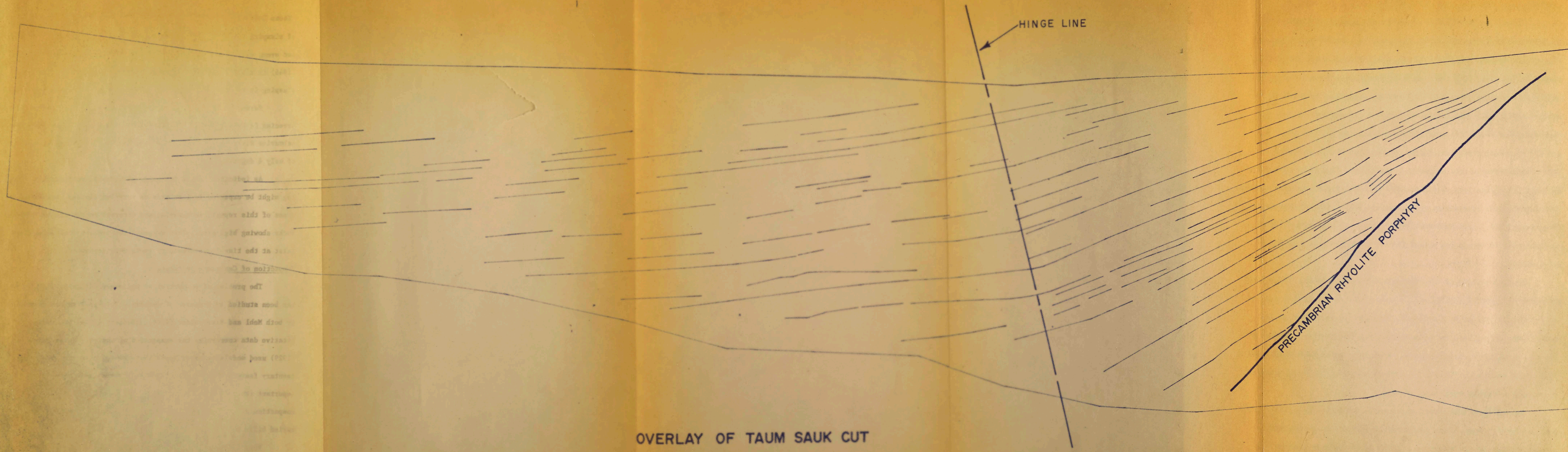
Another characteristic shared by rocks showing peripheral dips is that they dip at an angle substantially lower than that of the Precambrian surface on which they rest. This can be readily observed in Figure 32, a composite photograph of the Taum Sauk Cut, and in Figure 29, a cross-section of Czar Knob.

No slumping whatever was observed in rocks displaying the high dips in any of the study areas. The pebbles of a flat-pebble conglomerate in the Czar Knob area showed orientation of long axes of the pebbles parallel to the dip of the rocks. Bedding planes and fine lines of stratification in all strata displaying high dips appear regular and normal.

Certain inconsistencies appear in the concept of "initial dip" as supported by Bridge and Dake. According to a definition of initial dip offered on page 134 of this study, the layers of sedimentary rocks should be "parallel with the surface of deposition [Precambrian surface] unless subsequently altered by differential compaction or other deformational processes." The strata overlying the Precambrian surface where observed in areas of this study, and especially in the Taum Sauk area and the Czar Knob area, are clearly not parallel to the underlying Precambrian surface. The sedimentary strata have dips whose values are at least 20 degrees less than those of the underlying Precambrian surface. The slopes of the Precambrian surface at the north flank of Czar Knob (56 degrees) and in the Taum Sauk Cut (44 degrees) both exceed the maximum angle of repose for unconsolidated sediments (see page 134 of this study).

Another problem of the "initial dip" concept is the "hinge line" described in an earlier paragraph. By what process involved in initial dip could this feature be developed? This feature is present at the north flank of Czar Knob in sedimentary rocks that overlie a uniformly steeply dipping Precambrian surface. According to the concept of initial dip, if the underlying Precambrian surface continues to dip steeply, so should the overlying sedimentary strata.

As mentioned in an earlier paragraph, no indications of slumping were observed in rocks closely adjacent to buried Precambrian hills, even where dips exceed 30 degrees. Lahee (1952, p. 299) reports "mud and clay may slide on slopes of only 2 degrees or 3 degrees." Several of the beds exposed in the Taum Sauk Cut consist entirely of shale.



OVERLAY OF TAUM SAUK CUT
SHOWING
SELECTED BEDDING PLANE TRACES AND THEIR RELATIONSHIP TO BURIED PRECAMBRIAN TOPOGRAPHY

FIGURE 83

These beds might be expected to show slump features and provide planes of slumping for overlying sediments. Yet the beds are entirely regular and even, and in all respects similar to flat-lying sediments. Fairbridge (1946) in a detailed study of submarine slumping, maintains that gravity slumping is inevitable with normal sediments on a slope of 5 degrees.

Snyder and Odell (1958) have studied the origin of sedimentary breccias in the Southeast Missouri Lead District. They describe extensive submarine slumping of lime muds of the Bonneterre Formation on slopes of only 4 degrees.

As indicated in the foregoing paragraphs, considerable slumping might be expected in lime muds on very low slopes. Yet in the study areas of this report, no slumping was observed in any of the sedimentary rocks showing high dips. This suggests the present steep dips did not exist at the time the sedimentary rocks were deposited.

Compaction of Carbonate Sediments

The problem of compaction of sediments adjacent to a rigid core has been studied by a number of workers. This problem was discussed by both Mehl and Blackwelder (1920). Hedberg (1926) provided quantitative data concerning the compaction of shales. Nevin and Sherrill (1929) used models in experiments that demonstrated some of the sedimentary features that develop through differential compaction. An important study by Athy (1930) contains equations, based upon the compaction of shales, that can be used to predict dips surrounding buried hills.

Very little was known of the compaction of carbonate sediments at the time Dake and Bridge made their studies of peripheral dips in the Central Ozarks. They assumed a compaction of about 5 percent for carbonate rocks during lithification. Much additional work has been completed concerning limestone diagenesis in the years since publication of the reports of Dake and Bridge. Many different types of limestone, having different depositional histories have been recognized. Each of these might be expected to undergo varying amounts of compaction during diagenesis.

Before some conclusion can be reached regarding degree of compaction of carbonate rocks showing high peripheral dips in the areas of this report, the type or types of carbonate sediments involved must be considered.

Bridge (1930, p. 156) states:

> The limestones and dolomites involved in peripheral dips are extremely fine grained plastic sediments, and were doubtless quite similar to the lime sediments, now accumulating on the Great Bahama Banks.

Bridge (1930, p. 161) further identifies these ancient sediments as similar to drewites (fine grained lime ooze).

Cloud and Barnes (1957) compare Early Ordovician carbonate rocks of Central Texas with those now forming on the great Bahama Banks. These rocks of Central Texas are similar lithologically, and in part stratgraphically equivalent to rocks showing high peripheral dips in the areas of this report.

This writer concurs with the comparison of Late Cambrian and Early Ordovician rocks of the Central Ozarks with lime muds now forming on the Bahama Banks. Most carbonate rocks in the areas of this report, based on detailed observations of texture and other sedimentary characteristics, seem to have been originally lime muds. This is particularly true of carbonate rocks examined in detail in the Taum Sauk Cut.

To what extent are lime muds compacted during lithification? Important data have become available on this problem since Bridge cited a value of 5 percent in his report in 1930.

An excellent study of this problem was completed by Terzaghi (1940). She obtained samples of lime mud (drewite) from the Bahama Banks and subjected them to compacting pressures under carefully controlled laboratory conditions. Her experiments showed that lime muds may undergo almost as much compaction as a lean shale (about 25 percent.) Terzaghi derived equations, based in part on her experimental results, for calculation of amount of compaction to be expected for a lime mud under varying compacting pressures. She calculated dips that might be produced by compaction of lime mud adjacent to a rigid core, and compared them with actual dips of more than 30 degrees adjacent to a rigid biohermal reef core exposed in Indiana. Her calculated dips, and dips exposed adjacent to the biohermal reef both show development of a "hinge-line" similar to ones discussed in a preceeding section of this chapter. Terzaghi concluded that compaction of lime mud caused the development of dips of more than 30 degrees adjacent to the biohermal reef.

Snyder and Odell (1958, p. 915) present important evidence concerning compaction of lime mud. In their study of sedimentary breccias, they present proof of very substantial compaction of lime muds, and cite it as the mechanism for formation of slide breccias. Snyder and Odell state:

> Carbonate sands of the banks and rigid reef framework were probably only slightly compacted; the fine-grained basin sediments probably were strongly compacted. Compaction, beginning in each layer of mud as soon as it was buried by the next succeeding layer, would decrease gradually as basin sediments passed by intertonguing and intermixing into the bank facies. The graduation in degree of com-

> paction would most strongly influence attitude of beds on the flanks of the depositional highs, and at these positions original dips would be greatly steepened.

Robertson, (1965, p. 170) obtained samples of lime mud from near Andros Island in the Bahamas, and subjected them to pressures up to 30 bars. He states:

> Consolidation is effected by compaction of grains, recrystallization, and by increase of intergranular bonding. Pressure of 30 bars causes a compaction of about 20 percent for a given temperature.

Conclusion

It appears likely, in consideration of the foregoing evidence, that the peripheral dips are not largely those of the original surface of deposition, as supported by Dake and Bridge. Instead the writer believes the original dip was probably less than 4 degrees. As sedimentation progressed, these very low original dips were slowly increased by compaction. Sufficient lithification must have occurred early during compaction to prevent slumpage. With greatly increased load of overlying sediments, these carbonate rocks were compacted until the present steep dips, such as those exposed in the Taum Sauk Cut, were developed.

The importance of compaction in development of peripheral dips is well shown in the Caledonia area. Here, very low dips are observed in sandstone beds of the Lamotte Formation, even closely adjacent to Precambrian hills. In units of the Bonneterre Formation the dips are generally steeper. Sandstones are known to undergo relatively little compaction, whereas dolomite, as suggested from the foregoing section, probably undergoes greater compaction. Thus the contrast in degree of dip between units of the Lamotte Formation and the Bonneterre Formation can be explained by varying rates of compaction.

Moderate thinning of individual beds within sedimentary strata of the Taum Sauk Cut is shown (Figure 83) as the Precambrian hill is approached. Such thinning is also recognized in sedimentary strata at Czar Knob. Both Dake and Bridge (1930) recognized this phenomenon adjacent to buried or partly resurrected Precambrian hills.

The thinning of sedimentary strata is believed by the writer to be related to the low original dip of sedimentary strata near buried hills. As fine lime sediment was deposited on the original gently sloping surface of deposition, normal current winnowing down slope probably brought about removal of some sediments from up-slope areas and continually redeposited them down slope and farther away from the Precambrian hills. The much thicker sedimentary section in valley or basinal areas between Precambrian hills, reported by both Dake and Bridge (1930), is believed due to this process.

DEPOSITIONAL ENVIRONMENTS ADJACENT TO PRECAMBRIAN HILLS

Precambrian hills considered in this study appear to have influenced or controlled depositional environments in their vicinities to varying degrees. This influence appears to have been largely dependent upon a depth of submergence of the buried hill at time of deposition of surrounding sediments. Where the Precambrian topography apparently was above wave base, or entirely emergent, a profound influence on adjacent sedimentary environments is noted. Where the Precambrian topography was apparently submerged below wave base, little or no influence on adjacent sedimentary environments is noted. Buried hills of the six study areas of this report are classified in the following paragraphs, according to the degree they seem to have influenced adjacent sedimentary environments.

Intensive Influence

Sedimentation of the Taum Sauk area seems to have been closely controlled by large ridges of Precambrian rocks that almost certainly stood as islands in Late Cambrian seas. The Precambrian rocks at times contributed large volumes of fragmented rhyolite porphyry to sediments in the western half of the Taum Sauk area. Crossbedding in carbonate rocks in the western half of the Taum Sauk area indicate these rocks were deposited at or near wave base. The relatively pure white dolomite of the eastern half of the Taum Sauk area suggests deposition in a sheltered environment, where wave action was greatly restricted.

The fringing algal reef, well exposed at the north flank of Czar Knob, clearly reveals the important influence this Precambrian hill had upon sedimentation in its vicinity. Shallow water is necessary for the development of such a clearly recognizable reef structure. A flat-pebble conglomerate in part of the Davis Formation immediately adjacent to the Precambrian hill suggests the hill and surrounding sediments stood above sea level, at least for a limited time. Small fragments of arkosic material, found in rocks of the Davis Formation in the vicinity of Czar Knob, suggest moderate wave action on the partly exposed knob.

Moderate Influence

Sedimentary rocks of the Caledonia area show at least moderate influence of the large Precambrian ridge present in the area. A chert and rhyolite porphyry conglomerate (Figure 59) apparently was formed by vigorous wave action upon exposed Precambrian topography. Arkosic facies of the Lamotte Formation suggest local derivation of this material by wave action. As sedimentation progressed in the Caledonia area, apparently less and less influence was exerted by Precambrian topography. The Bonneterre Formation is entirely free of arkosic material where observed in outcrop and probably was deposited below wave base.

Limited or Unknown Influence

In the Eminence Knob area, outcrops of the Eminence and Potosi formations were observed directly in contact with rhyolite porphyry of Eminence Knob at numerous localities. These sediments are almost entirely free of arkosic materials and have even, regular lines of stratification. With exception of a single arkosic zone at one outcrop, the lithologies and textures of these sedimentary rocks are similar in all aspects to those observed elsewhere at locations much farther removed from the knob. If any significant influence was exerted by Eminence Knob on depositional environments in its vicinity, such influence was not apparent from examination of the outcrops.

At Little Pilot Knob, no sedimentary rock outcrops were observed immediately adjacent to trachyte porphyry. At outcrops somewhat farther removed from the knob, the lithology, texture, and bedding of sedimentary rocks was entirely normal and similar to that seen elsewhere in the area. Nothing was observed to suggest unusual or anomalous depositional conditions. Nothing is known of depositional conditions immediately adjacent to Little Pilot Knob, where no outcrops were observed.

Very little is known on depositional environments adjacent to the buried rhyolite porphyry hill in the Sullivan area. The few observed outcrops are relatively far removed from the indicated location of the hill. At these outcrops, nothing was seen to indicate conditions different from those elsewhere in the Central Ozarks.

General Conclusions

Ojakangas (1960) and Carver (1961) studied distribution of depositional facies of the Lamotte and Roubidoux formations in southeastern Missouri. Ojakangas recognized a facies change from orthoquartzite to arkosic sandstone in the Lamotte Formation adjacent to Precambrian hills. He identified the source of the orthoquartzite as Siouxia, to the northwest, and the Wisconsin arch, to the north. He believes much of the arkosic material is locally derived.

Carver (1961, p. 90) indicates the Ozark dome continued to be important in control of sedimentation in Roubidoux time, but only in a broad sense. He recognizes a low shoal or island province adjacent to the present granitic outcrop of the Ozark dome. The Taum Sauk area, Eminence Knob area, and the Caledonia area are included in this province. To the northwest of the present granitic exposures, Carver recognizes a back-reef lagoon facies where sand comprises more than 30 percent of the formation. The Little Pilot Knob area, the Czar Knob area, and the Sullivan area are included in this facies.

This writer agrees with Carver's identification of facies distribution in four of the six areas of this report. However, in view of observations made by the writer it seems that the area of Czar Knob would be more appropriately included in the low shoal or island province. In the case of Eminence Knob, field evidence observed by the writer suggests this area might be logically included in the back-reef lagoon province.

PERSISTENCE OF STRUCTURAL RELIEF IN SEDIMENTARY ROCKS OVERLYING PRECAMBRIAN HILLS

Bridge (1930, pp. 163-164), in his report on the Eminence and Cardareva quadrangles, discusses the problem of persistence of structural relief in sedimentary rocks overlying buried Precambrian hills. He reports pronounced relief up to 750 feet above a buried hill, and concludes that 900-1,300 feet of sedimentary rocks are required to obliterate evidence of a buried hill.

In the Little Pilot Knob area 260 feet of structural relief is noted on the top of the Potosi Formation, near the crest of a buried hill. This buried hill is believed to lie no deeper than 500 feet below the surface. Structural relief of about 250 feet was measured in sedimentary rocks adjacent to Czar Knob. Structural relief of more than 100 feet is noted in sedimentary rocks adjacent to rhyolite porphyry in the Taum Sauk Cut.

In the Sullivan area very little structural relief was observed on the Roubidoux Formation, even though rhyolite porphyry is present at a depth of only 25 feet in the central part of the area.

The author believes that no simple rule can be stated concerning persistence of structural relief above buried hills. Four interrelated factors are involved:

(1) Areal extent or size of the buried hill
(2) Height of the buried hill
(3) Steepness of sides of a buried hill
(4) Compactibility of sediments covering the buried hill

Of these four factors, the author considers compactibility of sediments to be of greatest importance. Hills buried by fine lime muds would be expected to show considerably greater and more persistent structural relief than those buried by lime sands. Buried hills with relatively steep flanks probably develop greater and more persistent structural relief than do those with broad, gentle flanks. It is presently impossible to quantitatively evaluate all of these factors separately.

In general, the writer agrees with Bridge's conclusions that structural relief extends upward above buried hills through a considerable thickness of sediments. It is possible that an even greater thickness of sediments than 1,300 feet, as cited by Bridge, might be required to eliminate all evidence of a buried hill. Smoot (1958), in a study of structural relief developed in sediments above Silurian reefs in Illinois, reports small but measurable relief through more than 1,500 of overlying sedimentary rocks. His work shows that expression of structural relief persists, even through a major unconformity at the base of the Pennsylvanian System.

However, as shown by Snyder and Odell (1958), some structural relief in sediments can be developed due to varying rates of compactibility of carbonate sediments. Such relief, due to varying rates of compaction of sediments, could be confused with relief due to buried Precambrian topography.

MAGNETIC CHARACTERISTICS OF PRECAMBRIAN HILLS

Variation in Magnitude of Anomalies

The extreme variation in magnitude of anomalies associated with buried hills is shown very strikingly in the areas of this study. These range from high magnitude anomalies (more than 700 gammas) associated with trachyte porphyry of Little Pilot Knob, to extremely low magnitude anomalies such as those at Czar Knob (30 gammas) and in the Sullivan area (50 gammas). This variation is determined, with other factors being equal, by the variation in magnetic susceptibility of the Precambrian rocks. As shown by Allingham (1964), there is a substantial variation in magnetic susceptibility of Precambrian rocks of southeastern Missouri. The areas of this report are considered in the following paragraphs according to magnitude of anomalies associated with Precambrian hills within their boundaries.

High Magnitude Aeromagnetic Anomalies (More than 500 gammas). The Little Pilot Knob area contains anomalies of the greatest magnitude noted in this study. These anomalies are due to the high magnetic susceptibility of the Precambrian trachyte porphyry. Much lower and smaller hills of similar trachyte porphyry might be easily recognized by their associated anomalies on aeromagnetic maps.

Medium Magnitude Aeromagnetic Anomalies (100-500 gammas). The Caledonia area contains anomalies ranging from about 100 to 500 gammas. The magnitude of these anomalies can be attributed in part to magnetic susceptibility, and in part to greater elevation of the Precambrian rocks. Susceptibility of rhyolite porphyry of the Caledonia area is lower than the trachyte porphyry of the Little Pilot Knob area. Smaller and lower hills than those of the Caledonia area composed of similar rhyolite porphyry would be somewhat difficult to recognize on aeromagnetic maps.

Low and Very Low Magnitude Aeromagnetic Anomalies (Less than 100 gammas). Czar Knob offers a typical example of a low magnitude anomaly. The crest of this large granite hill stands 1,000 feet above sea level, and more than 800 feet above the lower level of the Precambrian surface. Yet, the total intensity aeromagnetic anomaly associated with this hill has a magnitude of only about 30 gammas. This low magnitude is clearly due to the very low magnetic susceptibility of the Czar Knob Granite.

Anomalies of up to 50 gammas are noted in the Taum Sauk area. These low values are also believed to be due to lower magnetic susceptibility. No anomaly whatever is indicated on the aeromagnetic map of Sullivan area for the rhyolite porphyry knob encountered in drilling at a depth of 25 feet. However, an anomaly of about 50 gammas for this feature was measured in a ground total intensity magnetic survey of the area.

A buried hill composed of granite similar to that of Czar Knob but moderately smaller, would be very difficult to identify on aeromagnetic maps.

Exploration for Buried Hills by Magnetic Methods

In exploration for Precambrian hills by magnetic methods, a clear understanding of the magnitude of anomalies associated with the hills is needed. This is largely a function of magnetic susceptibility of the Precambrian rocks.

Even relatively small and deeply buried Precambrian hills with a susceptibility of more than 5.00×10^{-3} cgs units probably could be recognized on aeromagnetic maps. Small, deeply buried Precambrian hills with susceptibilities of about 2.50×10^{-3} cgs units would be more difficult to recognize. Small deeply buried Precambrian hills with susceptibilities of less than 1.00×10^{-3} cgs units probably could not be recognized on typical aeromagnetic maps.

A more quantitative approach is possible by use of the surface integral method, discussed in an earlier chapter. Calculations could be completed for buried hills of varying sizes, shapes, depths of burial, and magnetic susceptibility. From these calculations computed aeromagnetic maps such as those shown in Figures 73 and 75 could be prepared.

Such maps would clearly show the magnitude of anomalies to be expected in association with various buried Precambrian hills.

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He accepted employment as exploration geologist with The California Company, New Orleans, Louisiana, in 1956. In the years from 1956 until 1960, he was involved largely in geological and geophysical exploration for petroleum in offshore areas of Louisiana.

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